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A PRACTICAL TREATISE

ON

RAIL-ROADS AND CARRIAGES,

SHEWING THE

PRINCIPLES OF ESTIMATING

THEIR

STRENGTH, PROPORTIONS, EXPENSE,

AND

ANNUAL PRODUCE,

AND

THE CONDITIONS WHICH RENDER THEM

EFFECTIVE, ECONOMICAL, AND DURABLE;

WITH THE

THEORY, EFFECT, AND EXPENSE OF STEAM CARRIAGES,
STATIONARY ENGINES, AND GAS MACHINES.

ILLUSTRATED BY FOUR ENGRAVINGS AND NUMEROUS USEFUL TABLES.

BY THOMAS TREDGOLD, CIVIL ENGINEER,
MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS, &c.

"Our present modes of conveyance, excellent as they are, both require and admit of great improvements."—QUARTERLY REVIEW.

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1835.

TO

THOMAS HOBLYN, ESQ.

FELLOW OF THE ROYAL SOCIETY,

VICE-PRESIDENT OF THE SOCIETY

FOR

THE ENCOURAGEMENT OF ARTS, MANUFACTURES,

AND COMMERCE,

ETC. ETC. ETC.

AS AN ACKNOWLEDGMENT OF HIS

LIBERALITY IN PATRONISING THE CULTIVATORS OF

MECHANICAL KNOWLEDGE,

THIS WORK,

ON THE PRINCIPLES AND CONSTRUCTION OF RAIL-ROADS,

IS GRATEFULLY INSCRIBED,

BY THE AUTHOR.

PREFACE.

Every practical system of conveyance must be more or less a subject of interest in a commercial country; and if each system were carefully investigated and compared with others of a similar nature, and the peculiar advantages, and the limits which restrict the application of each system, were considered, the result of such research would be useful at all times, but particularly so at present, when there is a surplus of capital, which might be directed with advantage to improve the internal communication of the country.

This small treatise was commenced with a view to accomplish the object just stated, as far as relates to Rail-roads; and I trust it will shew, in a clearer manner than has hitherto been done, the cases where Canals may be employed with advantage, and where Turnpike-roads are most economical, and the proper objects and economy of the intermediate system of conveyance by Rail-roads.

But, in order to arrive at proper data to cal-

culate from, it was necessary to enter into an experimental investigation of the subject, on such a scale as would enable me to exclude extraneous circumstances, and obtain results that would approximate to the average of actual practice; for those who have the means have forborne to give the average work done for a considerable period on the large scale. Knowing the uncertainty of dynamometrical trials, and that an experimentalist must have an invariable force, with the power of frequently repeating and comparing his trials by different modes, till he be completely satisfied that he has arrived at the true measure of the quantities it is his object to ascertain—and that these are not easily obtained in public experiments where the conductor is exposed to more than ordinary interruption,—I made a set of experiments, on a scale sufficient to establish the facts I wished to arrive at, though they might with some advantage have been on a larger scale and more varied in the parts: only the reader will recollect they are the contributions of an unassisted individual; and if it were not that they employed those hours which are usually devoted to relaxation, these sheets could not have been written. Besides

the questions which arise respecting Railways, (and it is a subject rather fertile in matter for useful research,) several others are considered: instances will be found in the theory of Gas Machines, and in the inquiries relative to the nature, power, and properties of Steam Engines. It might have been expected that all such inquiries had been already made, and long ago in the hands of those interested in these powerful and economical first movers of machinery: so far, however, is this from being the case, that it is even questionable whether any thing of importance has been done towards the theory of the Steam Engine; and certainly nothing has been published except such as would rather mislead than assist in bringing it to perfection. That often repeated theory of the Expansive Engine, which is the joint production of Mr. Watt and Dr. Robison, neglects the very circumstances which limit its application in practice. Indeed, the relation of parts, which is essential to the perfect action of a Steam Engine, is only so far known as has been developed by repeated trials; and no one appears to have attempted to ascertain the proportions which will give a maximum of effect under given con-

ditions. It is not in theoretical investigation alone that the defect consists, for even facts and observations are wanting. The specific heat of steam in different states has not been determined, and therefore there was nothing to check the extravagant expectations which were lately entertained on the advantages of high pressure steam. One is almost led to imagine that this is a subject beneath the notice of the men of science in this country, and that nothing less than scaling the heavens will now satisfy their enthusiasm. If they be insensible to its value, it is not so with others; for it has been deemed a happy circumstance that we live in an age which gives us the benefits arising out of the invention of the Steam Engine. Its powers, its pliability, and its importance to the welfare of this country, have been expatiated on and acknowledged by all parties; and while I recollect with pride that it is of British invention, I cannot but regret that its principles have not been developed by British talent.

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CHAPTER I.

Nature of Rail-Roads—Advantages of Internal Communication—Roman System of Roads — Relative Advantages of Turnpike-Roads, Rail-Roads, and Canals — Existing Rail-Roads in England — In Scotland—In Wales.

THE principal object in constructing a rail-road is to form hard, smooth, and durable surfaces for the wheels of the carriages to run upon. These surfaces consist of parallel rails of iron, raised a little above the general level of the ground, with a gravelled road between the rails; consequently, a rail-road combines the advantages of good foot-hold for horses and of smooth and hard surfaces for the wheels to roll upon. The wheels of rail-road carriages are furnished with proper guides to keep them on the rails; and the circumferences of the wheels are made hard and smooth. Plate I. fig. 1, represents a double rail-road with carriages on it; and a part of

the road is supposed to be taken up to show its construction (see the description opposite the Plate.)

The facility with which a heavy carriage may be moved on a road constructed in this manner, renders it an object of surprise that an arrangement so simple, economical, and efficient, has not been more generally employed.

The idea of forming smooth surfaces for carriage wheels to roll upon is not a modern one, but no horse could draw with advantage on a smooth pavement; hence, in Florence, where the wheel-tracks are paved with hard marble, wrought smooth and level, the horse-paths are of ordinary paving.

At an early period, a similar advantage was obtained in our own country, by putting down rails of hard wood for the wheels of waggons to run upon; and more recently rails of cast iron have been employed, and with more advantage; for cast iron is much harder and more durable than even the marble wheel-tracks of the Italians.

By using iron, we obtain a smooth, hard, and even surface, at an expense comparatively small, and the moving power has very little more than the friction of the axis to contend against. A carriage moving under such circumstances bears the nearest analogy to a body impelled on the smooth surface of ice, where it is well known that the velocity which may be given by a small power is immense; what the rails want in smoothness being compensated for by the use of wheels. The effect of the air's resistance, and the law of increase of friction, is the same in both cases. These important advantages of rail-

roads were foreseen some years ago by Dr. Thomas Young; for he concludes his notice of them in these remarkable words: "It is possible that roads paved with iron may hereafter be employed for the purpose of expeditious travelling, since there is scarcely any resistance to be overcome, except that of the air, and such roads would allow the velocity to be increased almost without limit."*

In discussing the merit of rail-roads, we have to compare them with turnpike-roads and with canals. Rail-roads give the certainty of the turnpike-road, with a saving of seven-eighths of the power; one horse on a rail-road producing as much effect as eight horses on a turnpike-road. In the effect produced by a given power, the rail-road is about a mean between the turnpike-road and a canal, when the rate is about three miles per hour: but where greater speed of conveyance is desirable, the rail-road equals the canal in effect, and even surpasses it.

Speed and certainty are of such primary importance in commerce, that a small increase of expense is not a material object.

Certainty of supply must tend much to diminish the fluctuation of prices, and remove those alternations of glut and scarcity which are perpetually occuring in the markets, from contrary winds, frosts, floods, &c. Every thing which tends to render the conveyance of goods certain, must lessen their expense to the consumer, by diminishing the amount of dormant capital, and the necessity of keeping

* Nat. Phil. vol. i. p. 219. 1807.

large stores in expensive warehouses: and, with a good system of conveyance, when a sudden call does take place, the whole stock of the country becomes available. The motives which now operate in accumulating people together in large towns, it is probable, will also be less powerful, in proportion as facility and certainty of intercourse increase.

But these remarks extend only to the present state of trade; its extension and economy in Britain are of still greater importance. We must ever regard ourselves as contending in rivalry with other nations; and whatever enables us to supply home and foreign markets at a lower rate with articles of superior excellence, must add to the prosperity and wealth of the state.

To improve the interior communication in this country must be productive of much good, by equalising the distribution of agricultural produce, and allowing that of those districts, to which nature has been most bountiful, free access to market. There must necessarily be a very wide difference in the nature of the soils in any country of considerable extent, and it is extremely improbable that the best is most favourably situated for yielding a fair profit on its produce, without the assistance of artificial means of sending that produce to the places of demand. And it is evident that, unless some easy mode of conveyance be resorted to, the demand must be supplied at a great expense from inferior soils, and, of course, from such as require a greater capital to cultivate them, without being more productive to the land-owner, while they are also less certain of

yielding a sufficient quantity to replace the capital expended, and afford the ordinary rate of profit.

A cheap and regular mode of conveyance, besides rendering the produce of fertile land accessible at a less price to any portion of the community, also affords new markets for other articles; it creates new sources of exchange and supply, and causes the advantages of labour and industry to spread, and expel the idleness and indifference which engraft themselves among those people who, without such means, barely obtain the common necessaries of life; for the ordinary mode of land-carriage makes every heavy commodity so expensive, that the inhabitants of inland districts are limited to what nature furnishes them with. In many places they are nearly destitute of fuel, and while moderate exertion gives them the scanty supply of comforts within their reach, their utmost efforts scarcely do more; and therefore they sink into that languid state of indifference which we find so generally prevalent in such countries.

It is true that the construction of roads, rail-ways, and canals is expensive: but under proper arrangement their formation might furnish a considerable degree of employment for the labouring poor, and thus be a relief to the parishes these roads would ultimately benefit. Most of the work in constructing rail-roads is of a kind favourable for letting, and of such a description that any person may be set to work at it.

The construction of good public roads was considered an object of such primary importance by the

ancient Romans, that all the chief cities of their vast empire were connected by roads far superior to any that have been executed in later times, and of a much more expensive kind than the best rail-roads in this country. The Roman roads were made so firm and solid that they have not entirely yielded to the dilapidations of fifteen centuries. They rendered an intercourse with the most distant provinces easy at all times, and rapid when occasion required. These roads ran nearly in direct lines from city to city, and have been the subject of universal astonishment and admiration. Natural obstructions were removed or overcome by the efforts of labour or art; whether they consisted of marshes, lakes, rivers, or mountains. In flat districts the middle part of the road was raised into a terrace which commanded the adjacent country. It was formed of different layers of stones and gravel, bedded in excellent cement, the upper surface being paved with stone. Near the capital the pavement was of granite; in other parts hard lava was used, worked in irregular polygons, and so accurately joined that Palladio thinks they must have used sheets of lead as moulds to take the various angles and contours for fitting them together. In mountainous districts the roads were alternately cut through mountains, and raised above the valleys, so as to preserve either a level line or a uniform inclination, as was most adapted for the route. They founded on piles where the ground was not solid, and raised the road by strong side-walls, or by arches and piers where it was necessary to gain elevation.

The Roman roads were much narrower than ours, the width of the carriage-way, as prescribed by the laws of the twelve tables, being only eight Roman feet; * but their carriages were also narrower than ours, the width of the wheel-track not being more than three feet. † The paved part of their great military roads was wider, being 16 Roman feet, with two sideways, each 8 feet wide, separated from the middle way by two raised paths of 2 feet each; so that the entire width of the principal military roads did not exceed from 36 to 40 feet. The whole depth of materials was about 3 feet, and built in a most solid manner.

There were 29 military roads leading from Rome, some of which extended to the extreme parts of the empire—their total extent being, according to Rondelet, 52,964 Roman miles, or about 48,500 English miles.

The construction of the Roman roads was an object of state policy: with us it is the commercial interest of the country which feels the important advantages of a secure, certain, and speedy system of intercourse for the disposal and exchange of commodities. And since it is desirable among the people of the same state, that all should enjoy as nearly the same advantages for trade as the nature of things will allow, the power of internal communication ought to be encouraged, and its benefits extended to every part of the country of which the

* The English foot is to the Roman foot as 1000 : 967

† Rondelet, l'Art de Bâtir, tom. i. p. 360.

agricultural, mineral, or manufactured products, are of sufficient importance to render the communication beneficial to the state.

Hitherto canals have been chiefly employed for the convenience of internal traffic; and where heavy goods are to be moved, they present such important advantages that the use of other modes of conveyance has been scarcely thought of till within the last two or three years. Now, intercourse by means of rail-ways engages a considerable share of attention; and their construction and use, and the means that may be adopted to improve them, will form the subject of this work.

Up to this period rail-ways have been employed, with success, only in the conveyance of heavy mineral products; and for short distances, where immense quantities were to be conveyed. In the few instances where they have been intended for the general purposes of trade, they have never answered the expectations of their projectors. But this seems to have arisen altogether from following too closely the models adopted for the conveyance of minerals, such modes of forming and using rail-ways not being at all adapted for the general purposes of trade.

When it is attempted to compare rail-ways with canals, or common roads, it must be obvious that each mode has its peculiarities; the same may be said of each line of traffic. Hence it is important that those peculiarities should be studied with care; and we shall endeavour to collect them in a concise form for the advantage of comparison.

It is necessary to premise, that in every species

of communication we should endeavour to combine economy, speed, certainty, convenience, and safety. It is also necessary to consider the peculiar requisites of each species of communication.

For a canal a competent supply of water is wanted, the quantity and expense of which is to be considered. A canal is limited to comparatively small changes of level; otherwise the delay and expense of lockage become too great. Canals are liable to frequent stoppages from frost, floods, repairs; and in all kinds of trade these stoppages create serious inconveniences, if not much disappointment and loss. Canals interfere much with the right of streams, and drainage; and consequently injure the property through which they are made, very considerably more than would be done by taking the part occupied by the canal. Both the first cost and the annual repairs of a canal exceed those of a rail-way; the excess differing according to the nature of the country. But in a country suited for a canal the difference of first expense is more than compensated, by a greater effect being produced by a given power on a canal than on a rail-way, provided the motion does not differ much from three miles per hour; and this renders a canal decidedly better for a level district. On account of the resistance increasing in the ratio of the squares of the velocities when bodies move in fluids, and also on account of the injury the banks would suffer by too rapid a movement of the water, the velocity of canal boats must be considered as limited to a speed not far exceeding that which they obtain at present; but on a rail-way a

greater velocity may be obtained with less exertion, even where animal power is employed.

A rail-road has more affinity to a turnpike-road than to a canal both in structure and application. It differs from a turnpike in requiring to be level or slightly inclined, the ascents and descents being effected by inclined planes, instead of the irregular undulations of the turnpike. To obtain these levels renders a rail-road more costly than a turnpike; for as to the expense of a rail-road itself, it will sometimes be less than a good turnpike-road in the same place; for the interest of the excess of capital expended on the road will be less than the excess of annual expense to keep the turnpike in repair. But a horse will draw eight times as much on a rail-road as on a turnpike-road when travelling at the same rate, and it is not improbable that the reduced price of conveyance will cause eight times the quantity of traffic.

In a rail-road for an unequal trade a descending plane in the direction of the greater traffic is desirable; the proportion of descent most favourable we shall shew in our third chapter, only noting here that it is frequently an important advantage in any place where there is much ascent to arrive at the matter to be conveyed; a canal can take no such advantage, it must be level. The ascents and descents by inclined planes are much more expeditiously effected than by locks, and are not so limited to change of level.

But the great advantage of a rail-way will consist in its affording the means of transporting heavy

goods with speed and certainty: if it be only so far as to double the speed of the fly-boats, it must be a material benefit. And recollecting that rail-roads are yet in an imperfect state, while the united talents of our civil engineers have been chiefly devoted to canals for about a century, we may confidently hope that there is yet scope for improvement; and we may fairly infer that for new works rail-roads will, in nine cases out of ten, be better adapted for public benefit than canals.

Before we enter upon the principal inquiries connected with the subject of rail-ways, an account of those which are now in use may be useful in preparing the reader for what is to follow. We wish first to shew what is done in practice, and then from reasoning and experiment to prove what may be done to amend or improve them.

Rail-ways in England.

The first rail-ways appear to have been used in the neighbourhood of Newcastle-upon-Tyne, about 1680. The rails were of wood, resting upon wooden sleepers; and in some places near the Tyne the same species are still in use. The wooden ones are however nearly abandoned for iron ones, and of the latter there are an immense number, branching in various directions from both sides of the Tyne to the various coal-works; and also several inclined planes on which the waggons are moved by stationary engines. The rails employed are all of the kind called edge-rails; and it appears from experiments, that on the

level rails, when they are in good condition, 1lb. will draw 170lbs., or one horse will draw 25,500lbs. including the weight of the waggon, at the rate of $2\frac{1}{2}$ miles per hour.*

The same kind of rail-ways and waggons are employed for conveying coals from the collieries to the river Wear at Sunderland, some of them extending to a distance of more than seven miles.

The Hetton rail-way is one of the principal ones; it is in length $7\frac{1}{8}$ miles; and on it a train of from 13 to 17 waggons is impelled by a loco-motive, high-pressure engine, called by the people there an "Iron Horse." (See fig. 2. plate I.) The train of 17 waggons, when loaded with their usual weight of coals, will be about 64 tons, and when empty about $18\frac{1}{2}$ tons; the waggons being stronger and heavier than the common coal-waggons. The total variation of level from the pit to the staiths is 812 feet, of which a part is accomplished by inclined planes, and the rest by a regular descent of 1 part in 335. The rails are of the edge kind, and are represented in Plate II. fig. 3, 4, 5, and 6. The extreme length of each rail is 3 feet 11 inches, and the breadth of the upper surface $2\frac{1}{2}$ inches: they join with a scarf joint. The rails of the straight parts of the rail-way weigh 61lbs. each; but this was found to be too slight for the curved parts, therefore the strength of the latter has been increased, and the weight of each rail is 72lbs. In some parts near the staiths we observed malleable iron rails, in 15 feet lengths, supported at every 3

* Description of Rail-Way on a New Principle, p. 29.

feet (see fig. 9 and 10). They are $3\frac{1}{2}$ inches deep in the middle between the supports, and $2\frac{1}{4}$ inches in breadth at the upper surface; one yard in length weighs about 28lbs.

The wheels of the coal-waggons are 2 feet 11 inches in diameter, with 10 spokes, and weigh $2\frac{3}{4}$ cwt.; and their axles are 3 inches in diameter, and revolve in fixed bushes.

The weight of the engine is about 8 tons (see fig. 2, Plate I.) It consists of a boiler 4 feet in diameter, with an internal fire-place. The smoke ascends from the fire by a chimney about 12 feet high: the lower 3 feet of the chimney is formed of sheet iron of 6lbs. to the square foot, and the rest of iron $2\frac{1}{2}$lbs. to the foot. There are two cylinders, which work alternately. The diameter of the pistons is 9 inches, and the length of the stroke 2 feet; the pistons make about 45 double strokes per minute. The steam is admitted to the cylinders by slide valves worked by eccentric wheels on the axis of the engine carriage. The pressure of the steam in the boiler is from 40 to 50lbs. on the square inch.

The wheels of the engine carriage are 3 feet 2 inches diameter, with 12 spokes in each, and each weighs $3\frac{3}{4}$ cwt. The axles are $3\frac{1}{2}$ inches diameter, and are connected by an endless chain working into a wheel on each axle, so that both the axles of the carriage may be turned at the same rate. The boiler is supported on the carriage by four floating pistons, which answer the purpose of springs in equalising the pressure on the wheels, and softening the jerks of the carriage. A floating piston is packed as the steam piston of a steam-engine, and has a

short piston rod of $1\frac{1}{2}$ inches diameter, which rests upon the brass bush, in which the axle of the wheel turns. The water in the boiler presses on the upper side of the piston; and whatever elevation or depression the wheel follows, the pressure upon it is nearly the same. This ingenious substitute for a spring, as well as the other peculiarities of this engine, were invented by Messrs. Losh and Stephenson, of Newcastle-upon-Tyne, and made the subject of a patent in 1816. A further description will be found opposite the Plate, with a more distinct reference to the parts of the engine. The engine is supplied with coals and water from a small carriage connected to it, called the *tender;* the water-barrel contains about a hogshead of water, and is supplied with *hot water* from stationary boilers placed at convenient situations by the way-side.

The carriages are impelled by one of these engines at the velocity of from $3\frac{1}{4}$ to 4 miles per hour. And at a colliery, where the expense of engine fuel is a trifle in comparison with the expense of horses, it is most likely to be economical. The engines, we understand, are proved once in a fortnight. The steam carriage is managed with considerable facility; and it either impels the train of waggons before, or draws them in train behind, at the pleasure of the attendant; and the whole assemblage in motion forms a striking and interesting object.

The immense advantage of even the wooden railways in the Durham and Northumberland coal-fields soon caused them to be imitated in the neighbourhood of Whitehaven, in Cumberland, where they were employed to a considerable extent, till super-

seded by the use of cast iron ones. From these places the use of rail-ways has gradually spread to Yorkshire,* Derbyshire, Wales, and Scotland: the most important lines we shall next proceed to notice; commencing with the most considerable one which has been laid down for the general purposes of trade.

Surrey Rail-Road or Tram-Road.

The Surrey rail-road commences on the south bank of the Thames, near Wandsworth, in Surrey, and proceeds in a south-easterly direction about 9½ miles to Croydon, and from thence in a more southerly direction 8½ miles to Merstham, making a total distance of about 18 miles. The Acts for this rail-road were obtained in the 41st, 43d, and 45th of Geo. III. (1800 and 1804.) It is a double rail-road with tram-rails (see fig. 18, Plate III.): the inclination is no where greater than 1 in 120, or 1 inch in 10 feet. The original rails consist of a flat plate 4 inches wide, and nearly an inch thick, with a ledge to guide the wheels, 3 inches deep by half an inch thick. They are considerably worn into furrows by the action of the wheels on the grit and mud which get into the wheel-track. The original rails having been found too slight, those now used for repairs are cast of the form represented in fig. 19.

The waggons weigh about a ton, and are 5 feet

* Smeaton, in a report dated 1779, states the circumstance of the first waggon-way in Yorkshire, for carrying coals to the navigable rivers, being laid within his remembrance. Reports, vol. iii. p. 412.

wide, 8 feet long, and 2 feet deep; they are allowed to carry 3 tons, and not exceeding $3\frac{1}{4}$ tons. The wheels are of cast iron, $1\frac{1}{2}$ inches in breadth at the rim, and 32 inches diameter: they revolve on conical axles, $2\frac{3}{8}$ inches diameter at the shoulder, and $1\frac{1}{2}$ inches at the linchpin.

When the southern part of the road was opened, in 1805, twelve waggons laden with stone, and weighing $38\frac{1}{4}$ tons, were drawn a distance of 6 miles down the inclination of 1 in 120 by one horse in 1 hour 41 minutes with apparent ease.* According to Mr. Palmer's experiments 1lb. will draw 60lbs. on a level part of the rails at the velocity of $2\frac{1}{2}$ miles per hour, or one horse of average strength will draw a total weight of 9000lb.† These results we shall compare in the fifth chapter, merely noticing here that one carriage is worked by one horse.

The Surrey rail-road being one of the few attempts to form public rail-roads for general use, the causes of its not having been so successful as to encourage others become an interesting subject of inquiry. It may in some measure be accounted for by the nature of the road itself; for the effect falls far short of that produced on the edge-rails, while it is equally expensive, and the carriages are heavy, and carry too small a quantity; hence, with the circumstance of the carriages being confined to the rail-road, which prevents goods being conveyed to their proper destination without reloading, the advantages are not equivalent to the increase of expense.

* Rees's Cyclopædia, art. CANAL.

† Description of a Rail-Way, p. 29, second edit.

In the application of rail-roads, as of canals, it must always be to move goods or materials from one depot to another; their distribution must be effected by other modes of conveyance; consequently, as a means of general trade, they are not likely to answer for short distances. But where a quantity of goods is to be merely transported from one place to another, it is extremely inconvenient to divide them in small loads. The carriages ought to be sufficient to take a considerable bulk in one load: it is then easily watched and attended to; there is more facility in packing, loading, and unloading; and one carriage may easily be contrived to carry a sufficient load, by making them with six or eight wheels, so that the stress on the rails by one wheel should not be more than the given quantity. For conveying loose minerals small waggons do best; they are then emptied with more readiness than larger ones; but it is difficult to stow heavy and bulky packages in small waggons; such packages will often be found to fill a small waggon, and yet not load it. The waggons of a rail-way for general trade should be at least sufficient to carry the load of an ordinary stage-waggon, and such a waggon on six wheels would render it unnecessary to elevate the load so high.

The coal-works near Leeds and Wakefield are connected with the neighbouring canals by numerous rail-ways, and the town of Leeds is supplied with coal from the Middleton coal-works by a rail-road on which the waggons are impelled by steam-carriages. These carriages differ from those used

in the neighbourhood of Newcastle and Sunderland; for, instead of depending upon the friction of the engine carriage-wheels for reaction, the rails of the rail-way have cogs or projecting teeth, into which toothed wheels, driven by the engine, work as a pinion works in a rack. This species of steam-carriage was applied by Mr. Blenkinsop in 1811. The boiler is supported by a carriage with four wheels, without teeth, and rests immediately upon the axles. The engine is a high pressure one, and has two working cylinders. The connecting rods give motion to two pinions by cranks at right angles to each other, and these pinions communicate the motion to the wheels, which work into the teeth of the rail-way by working into a toothed wheel on the same axis. An engine of this kind, when connected with a train of 30 coal waggons, each weighing more than 3 tons, moved at the rate of about $3\frac{1}{4}$ miles per hour.

When a toothed rack is employed, a train of carriages may be moved on a rail way having a greater inclination than when the friction of the wheels upon the rails is depended upon; but even with a toothed rack the inclination soon arrives at a limit beyond which it is dangerous to go: we shall shew the extent in both cases in the third chapter.

Dewsbury and Birstal Rail-way.—The object of this rail-way is to convey coals from the coal-works in Birstal parish to the vessels in the Calder and Hebble Navigation. Its extent is about three miles, and it was finished in 1805.

The Ashby-de-la-Zouch canal, which was opened in 1805, is terminated by a rail-way of $3\frac{3}{8}$ miles in

length, extending to the Ticknall lime-works in Derbyshire; another rail-way of five miles to Measham collieries; and one of $6\frac{1}{2}$ miles to the Cloudshill lime-works.

The Derby canal has several rail-ways that branch from it, viz. to Horseley collieries, to Smithy houses near Derby, 4 miles, and to Smalley mills, $1\frac{1}{2}$ mile.

Rail-ways also branch from the Cromford and Erewash canals; and the Charnwood Forest canal is connected with the river Soar Navigation by a rail-way $2\frac{1}{2}$ miles in length, with a rise of 185 feet, called the Charnwood Forest rail-way.

The Chapel Milton to Loads Knowl rail-way, branches from the Peake Forest canal at Chapel Milton in Derbyshire to Loads Knowl lime-quarries in the Peake, a length of about 6 miles, with an inclined plane 515 yards long, and 204 feet fall. It was conducted by Mr. Benjamin Outram, engineer.

The Lancaster canal rail-way extends from Clayton Green, across the valley of the Ribble, to the top of its opposite bank, $3\frac{1}{4}$ miles. The communication between the parts of the canal is effected by means of this rail-way, which has an inclined plane on each side of the valley, and the fall is 222 feet.

From the river Wye, near Mitchell Dean, a railway is laid through the Forest of Dean to Lydney on the Severn, with a branch by Colford to Monmouth. And in the same neighbourhood, another rail-way extends from the Severn, 5 miles, to the collieries in the forest.

The peculiar advantages of rail-ways for great changes of level, is no where more fully exemplified

than in the inclined planes of the Shropshire canal.

The Shropshire canal having to pass through a district where the changes of level were abrupt and considerable, it was thought expedient to adopt inclined planes for conveying the boats to different levels. The first inclined plane is 350 yards in length, and 207 feet in perpendicular height, with a strong double rail-road upon it, to admit boats loaded with 5 tons, and their carriages. The second plane is 600 yards in length, and 126 feet in height, and the third 320 yards in length, with 120 feet fall. The whole were designed by Mr. William Reynolds, who constructed a plane of the same kind in 1788, with a fall of 73 feet, for 8-ton boats.

In Cornwall, a rail-road, 5 miles in length, has been constructed, from the harbour of Portreth to the mines near Redruth.

And an extensive rail-way from Stockton by Darlington to the collieries on the south-west side of the county of Durham, is now nearly completed. It proceeds from Stockton in a westerly direction, and about 3½ miles from thence, a branch to the south, of 2 miles, leads off to Yarm; the main line passes close to Darlington, and about 4 miles beyond Darlington, a branch to the south, of nearly 2 miles, leads to Pierce bridge. About 5 miles further on the line, the Black Boy branch leads off in a north-easterly direction to the Black Boy and Coundon collieries; the extent of this branch is upwards of 5 miles. The main line continues past Evenwood to near the Norwood collieries, and returns in a north-easterly

direction to the Etherly and Witton Park collieries. The total extent of the main line is about 32 miles. It is formed with edge-rails; and in the last Act of Parliament for this rail-way, there are clauses to enable the company to make use of loco-motive engines.

These instances of the application of rail-ways in England, will furnish a tolerable idea of the utility of this increasing mode of conveyance.

Rail-Roads in Wales.

In Wales, the rail-roads communicating between the iron-works and coal-mines, and branching from the canals and rivers to the principal mining districts, are very numerous, and have proved very beneficial undertakings both to the constructors and the public. The main rail-roads are joined by many smaller private ones, commonly called tram-roads, which give a great facility for traffic, in a rugged country like it, where the common roads are very bad. In 1791 there was scarcely a single rail-way in South Wales; and in 1811 the complete rail-roads connected with canals, collieries, &c. in Monmouthshire, Glamorganshire, and Caermarthenshire, amounted to nearly 150 miles in length, exclusive of underground ones, of which one company in Merthyr Tidvil possessed about 30 miles. The quantity is daily on the increase, and we shall only have occasion to notice the principal ones.

In consequence of the upper part of the Cardiff, or Glamorganshire canal, being frequently in want of

water, the Cardiff and Merthyr rail-way or tram-road was formed parallel to it, for a distance of about 9 miles, chiefly for the iron-works of Plymouth, Pendarran, and Dowlais.

The Act of Parliament for this tram-road was obtained in 1794 (35th Geo. III.) by Messrs. Hompray, Hill, and Co.; and it appears to have been constructed under the first Act ever granted for this species of road. The width of the land allowed to be purchased was 7 yards, and the whole length of the line is about 26¾ miles. It is one of those cases where the ruggedness of the country renders any communication difficult; but there are certainly fewer difficulties to contend with in rail-ways than canals, in such districts.

It was on this tram-road that a trial was made of Trevithick's high pressure engine, on the 21st of Febuary, 1804, for drawing the carriages. The same species of engine has been more recently applied, with better success, by Blenkinsop and others.

The Aberdare canal, which branches from the Cardiff canal, is connected with the Neath canal by rail-ways, the communication being completed by an immense inclined plane, up which the waggons are drawn by a high pressure engine.

The Sirhoway rail-road, or tram-road, commences from the Monmouth canal, at Pillgwelly, and passing through Tredegar Park, up the Ebwy river, at Risca crosses that river by a bridge of 16 arches; and following afterwards the course of the river Sirhoway, by Tredegar and Sirhoway iron-works, to Trevill lime-works, a total distance of about 28

miles; and it is accompanied through all its extent by a good turnpike-road. From the Sirhoway rail-way there are branches to several collieries, one to the Romney iron-works, and others in two places to the Monmouthshire canal. One horse draws about 10 tons down this rail-way, and returns with the empty carriages. The Act was obtained the 42d Geo. III.

The Brinore rail-way also leads from it, and is continued over the Black Mountain to the vale of the Uske at Brecon, and from thence to Haye on the Wye. By means of this communication, the price of coals in the upper parts of the counties of Hereford and Radnor has been much reduced.

The Blaen-Avon rail-way also leads to the Monmouthshire canal; its length is 5½ miles, and it rises 610 feet in that distance, to the Blaen-Avon furnace.

The Caermarthenshire rail-road commences from the dock or harbour of Llanelly, and extends 15 miles, through a productive coal country, to the lime-works at Llandebie; and from the eastern side branch rail-ways to the extensive coal-works of General Waide. Its general objects are the export of coals, iron, lead, &c. The Act was obtained the 42d of Geo. III.

From Mr. Palmer's experiments it appears that 1lb. will draw only 59lbs. on a level part of this rail-way.*

The Oyster-mouth rail-way proceeds from Swan-

* Description of a Rail-way on a New Principle, p. 29, 2d edit.

sea, 7 miles along the coast, to the village of Oystermouth; it is intended chiefly for the carriage of limestone. Act 44th Geo. III.

Several other rail-ways communicate with the Swansea canal from the coal-works in its neighbourhood.

The Abergavenny rail-way proceeds from the Brecknock canal, and passes by a bridge over the Uske to Abergavenny. From the same canal there is a rail-way branch to Uske and to Haye, and various others to coal and iron-works; and at the iron-works near Pontypool there are some lofty inclined planes.

The Ruabon Brook rail-way commences from an extensive basin at Pontcysylte, on the north bank of the river Dee; it is a double rail-way, and proceeds with a gentle ascent past Mr. Hazledine's iron-works, and through numerous collieries to Ruabon Brook, a distance of 3 miles.

Of the Welsh railways, we shall only further notice the railway for conveying slates from the Penrhyn slate-quarries, because it differs from the ordinary railways. The rest of the rail-ways in Wales have flat or tram-rails, almost without exception.

Penrhyn rail-way, from the Penrhyn slate-quarries in Caernarvonshire to Port Penrhyn, extends a distance of $6\frac{1}{4}$ miles, and is divided into 5 stages; it has $\frac{3}{8}$ of an inch fall in 1 yard, that is 1 part in 96, and it has 3 inclined planes. This rail-way was begun in October 1800, and finished in July 1801. It has oval-formed edge-rails of cast iron, $4\frac{1}{2}$ feet

long, and 2 feet apart. (See fig. 7, Plate II.) Two horses draw 24 waggons one stage 6 times per day and carry 24 tons each journey, or 144 tons per day. The wheels of the waggons are of cast iron, 14 inches diameter, and weigh 35lbs.* According to Mr. Palmer's experiments, it requires 1lb. to draw 87lbs. on the Penrhyn rail-way, when the rails are level; † while on the edge-rails of Newcastle, 1lb. will draw 176lbs.; this difference arises from the smallness of the wheels used on the Penrhyn rail-way. But, imperfect as it is, it has been of great value to the proprietors of the slate-quarries, by saving an immense expense in horse labour. The carriages are very low, and apparently convenient for conveying slates short distances; in fact, they are rather trams than waggons.

Rail-Roads in Scotland.

Rail-roads have not yet been constructed of any great extent in Scotland, though some very considerable ones have been projected. They are, however, much employed for short distances at some of the principal coal-works and the like: the most considerable is that from Kilmarnock to the harbour of Troon, in Ayrshire, a distance of 10 miles.

Troon rail-road was formed at the expense of the Duke of Portland, the proprietor of the coal-fields in that part. It is a tràm rail-road, and is supposed to

* Repertory of Arts, vol. iii. p. 285, and vol. xix. p. 16. New Series.
† Description of a Rail-way on a New Principle, p. 29.

have been directed by Mr. Jessop, who was extremely partial to that species. Its chief use is for the carriage of coal and lime; in which articles a great trade is carried on by means of this rail-way. The size of the Kilmarnock coal-waggons is, on an average, length 80 inches, breadth 45 inches, and depth 30 inches; each contains 40 bushels of coal, equal to 32 cwt. of good coal, or 35 cwt. of malting coal. These waggons weigh about 13 cwt. when empty. Some horses take down 2, and others 3 loaded waggons; and the general inclination of the rail-way is 1 in 660. Various species of waggons however are used on it; even common carts are allowed to go upon it if the wheels be cylindrical, and no greater load on one pair than 28 cwt.*

Alloa colliery rail-way is about 2½ miles in length, with cast iron rails; each loaded waggon contains 1 ton of coals, and 1 horse draws 8 waggons on the rail-way.

Various other rail-ways are in use in the mining districts of Scotland, and chiefly of the edge kind; and those which have been lately constructed are in general of malleable iron. Mr. Stevenson says, that the establishment of the Carron Company's rail-way is understood to have reduced their average monthly expenditure for carriage from £1200 to £300.†

The reader will now have acquired some idea of the importance and economy of rail-ways, and will

* Art. Rail-way, Napier's Supp. to Ency. Brit. p. 415—417.

† Dr. Brewster's Edin. Ency. art. Rail-way, p. 304.

be in some degree prepared by the facts we have collected *, to enter a little more into the detail of this truly British system of constructing roads.

* For various facts relating to the rail-ways in the southern part of England, and the Welsh tram-roads, we are indebted to the excellent art. CANAL, in Rees's Cyclopedia, written by Mr. John Farey; and to the valuable art. NAVIGATION, INLAND, in Dr. Brewster's Edin. Encyclo. ascribed to Mr. Telford; in addition to the works already quoted.

CHAPTER II.

Of the different kinds of Rail-Ways, and their comparative Merits and Uses—Edge Rail-Roads—Tram-Roads—Single Rail-Roads.

THERE are but three distinct kinds of rail-ways. The oldest and most extensively adopted plan consists in laying rails of wood or iron for the use of carriages with guiding flanges on the wheels; these are now termed *edge rail-roads*, in consequence of the iron-rails being narrow and deep.

The next method differs from the first, in having the guiding flanges upon the rails instead of upon the wheels of the carriages; it gives the advantage of employing carriages that can be used where there are not rails laid down. Rail-ways of this kind are called *tram-roads*, from their being first used for running trams upon. The rails are also called flat or plate-rails.

The third method consists in employing a single rail for carriages with two wheels; the rail being raised above the surface of the ground, and the carriage suspended from it. This method is a recent invention, and promises to be an useful one: reserving, however, our remarks upon it for their proper place, we shall proceed to describe the kinds we have enumerated, and in the same order.

Edge Rail-Roads or Ways.

Edge rail-ways were first constructed of wood in the neighbourhoad of Newcastle, for the purpose of conveying coals to the side of the river Tyne; and, occasionally, these wooden rails were covered with plates of wrought iron in the parts liable to much wear. In adopting cast iron for rails in the same neighbourhood, the same kind of wheels, and the essential structure of the rails, were preserved, the sole difference being in the circumstances which the use of a new material rendered necessary. Figs. 3, 4, and 5, Plate II., shew the side view, the plan, and the cross section of a cast iron edge-rail, of the form which is adopted in the best rail-ways on the banks of the Tyne and Wear. The waggons run upon the rounded edge of the rail, which is smooth, and laid as even and regular as possible. The length of the rail is usually 3 feet, with a depth of about 4½ inches in the middle, and breadth of the top 2 inches; but in some rail-ways the rails are 4 feet long. The ends of the rails meet in a piece of cast iron, called a *chair*, (see fig. 6,) and the chairs are fixed to blocks of stone called sleepers, with a broad base, and weighing from 1½ to 2 cwt. These are firmly bedded in the ground, and adjusted to a proper plane for the road, before the chairs are connected to them. The goodness of the road depends much on fixing the sleepers in a sound, firm manner. Some variety has occurred in the form of the edge-rail in Wales; for the rails of the Penrhyn rail-way were

made at first of an oval figure, but it was found that the oval rail wore the concave rims of the wheels very fast into a hollow, fitting so close to the rail as to create much friction, and oblige them to change the wheels often. Hence they altered their rails to the form shewn in the section of the rail-road fig. 7, and the cross sills connecting them were at the same time made of cast iron, with dove-tailed sockets to receive the ends of the rails. The rails are 4 feet 6 inches long, and 2 feet apart. Each rail weighs 36lbs., each sill 14lbs., and each waggon carries 1 ton.*

The form of these rails is considerably inferior to that of the Newcastle edge-rails; the swell in the middle of the depth of the Penrhyn rail, collects the greatest quantity of iron to that part of the depth where it offers the least resistance.

The mode of connecting the two lines of rails by cross bars or sills of cast iron, may perhaps be used with advantage in other cases, but we think the connexion of the rails to the sills not so good as by means similar to the metal chair used for the other edge-rails.

Our rules for the strength and dimensions of the parts of cast iron rails will be found in chap. VII.

We have already noticed that malleable iron was occasionally used for protecting wooden rails, but it appears to have been first employed for the rails themselves by Mr. George Grieve, at Sir John Hope's collieries near Edinburgh; these were made of $1\frac{1}{4}$ inch bars, and used for very light work only.

* Repertory of Arts, vol. xix. p. 16.

Malleable iron rails of a stronger kind were used by Mr. Neilson, of Glasgow, for a rail-way on the property of the Earl of Glasgow, commencing at the Hurlet coal and lime-works, and extending to the Paisley canal, a distance of $2\frac{1}{2}$ miles. The length of each rail being 9 feet, it is supported at every 3 feet, and is $2\frac{1}{4}$ inches deep, and $\frac{3}{4}$ of an inch thick; the waggons carry about 35 cwt.*

Malleable iron rails, formed of rectangular bars, must obviously present too small a surface for the wheels to run upon, or otherwise require more material than it would be consistent with economy to employ; and to obviate this difficulty a patent was obtained by Mr. John Birkinshaw, of Bedlington Iron-works, Durham, for an improved form for the bars to be used as rails. It consists in giving the bar the form of a triangular prism, or such variation of that form as is best adapted for the purpose. Fig. 11 represents the section recommended by Mr. Birkinshaw, and he proposes that the rails should be 18 feet in length. Fig. 10 represents another form, which is evidently better. His suggestion respecting welding the joinings would rather be injurious than useful, owing to the expansion in length by variation of temperature.

The chief advantage of wrought iron rails is that of reducing the number of joints; and the difficulty of making the rails perfectly even at the joints has contributed much towards their introduction.

Edge-rails are most adapted for permanent works.

* Napier's Supp. to Ency. Brit. art. RAIL-WAY, p. 416.

They are of such a nature that ordinary carriages cannot be employed upon them; but on any rail-way where such carriages can be used, they must do more injury to the surfaces of the rails than will be equivalent to the advantage of suffering them to go there. Consequently, a rail-way with edge-rails is much more likely to be kept in good order than any other. It is of the utmost importance in a rail-way that the upper surface of the rails should be perfectly even and smooth; the very object of putting down rails is to obtain such surfaces; but they would be kept in order only a very short time if carts or waggons from a common road were allowed to turn on to them with wheels covered with gritty mud; while the temptation to use a rail-way in this manner is great; for the load which required a horse on the common road might be drawn by a man on the rail-way; thus enabling them to go at greater speed, and yet with less injury to the horses.

Tram-Roads or flat Rail-Roads.

The rails of tram-roads have always been formed of cast iron; planks of wood were used, indeed, for a similar purpose, and still are on some occasions, but we can scarcely consider them as forming a wooden tram-road. The tram-rail is, however, exceedingly convenient for temporary uses, and in its ordinary form, (see the section of a tram-road, fig. 18, Plate III.) it is much used in quarries, in mines, in forming new roads, and in digging canals;

in conveying large stones for buildings and various other purposes. Tram-rails are of a very weak form considering the quantity of iron in them, and in some works it has been found necessary to strengthen them, by adding a rib on the under side, (see fig. 19,) the rails used in repairing the Surrey tram-road are of this form. It certainly renders them much stronger than any other form we have seen. See Chap. VII.

As tram-rails are applied with so much benefit in forming temporary ways, the most convenient and ready mode of putting them down, is an object of some importance. The common method is, to fix them, with nails or spikes, upon cross sleepers of wood. The chief inconvenience of this plan is the difficulty of driving and drawing the nails, when they have to be changed.

For permanent roads, the rails are usually fixed by spikes driven into wooden plugs, previously inserted in the blocks of stone for supporting the rails. See fig. 18.

An attempt to improve the method of putting down tram-plates, by Mr. Le Caan, is the only one we know which gives any facility in taking up, or putting down the rails; and though it does not meet our wishes entirely, we will describe it here, as it may suggest something better.

Le Caan's Tram-Plates for Rail-Roads. — These tram-plates are contrived so as to fix one another without the aid of nailing. Fig. 21 is a longitudinal section of two plates placed on their stone blocks or sleepers, C D E; and fig. 20 is a plan of the two

plates. The plates are joined by a dovetailed notch and tenon; and an oblique plug is cast on each plate, which is let into the stone block or sleeper. But, for the advantage of taking up the plates to repair any defect, there are plates at every thirty yards, with perpendicular plugs, as at E; such plates are called stop-plates. Fig. 22 shews the end of a rail with the tenon which fits a corresponding notch in the end of the next rail, and the form of one of the oblique plugs. The diameter of the plug near the shoulder is $1\frac{1}{4}$ inches, at the point one inch; its length $2\frac{1}{2}$ inches, and its obliquity, shown in fig. 21, is about 8 degrees. A small groove in the whole length of the exterior of each plug is made to allow the water in the hole to expand in freezing, and it also serves to admit a wire to draw a broken plug out by. The holes for the plugs should be cut to the depth of 3 inches, by a standard gauge of cast-iron, and counter-sunk so as to allow the end of the plate to bed firmly on the block which supports it.

Fig. 22 is one of the ends of a tram-plate, in which H, shews the flanch or upright edge; I, the flat part or sole, on which the wheels of the waggons run; D, one of the plugs; and K, a projection behind, to render the plates firmer upon the blocks. The usual length of one plate, is 3 feet; the flanch H, is $1\frac{1}{2}$ inches high, the sole or bed $3\frac{1}{2}$ inches, or 4 inches broad, and $\frac{3}{4}$ of an inch thick, but these dimensions are varied according to circumstances; the most approved weight has been 42lbs. for each plate. The ends from which the plugs project, and in which the tenons and notches are made, should

be $\frac{1}{4}$ of an inch thicker than the other part of the plate.

The weight of the blocks, or sleepers, should not be less than about 120lbs. each; and some kinds of ground will require heavier.

In this method the wheels of the waggons cannot be obstructed by the heads of nails rising above the surface, and the blocks are not disturbed by fixing the plates; and when repairs are necessary, 25 yards of rail-road may be taken up and relaid in about 10 minutes; and, from the nature of the joint, it is difficult to deviate from a straight line. Where curved lines are necessary, the plates must be formed for the purpose.*

When tram-plates are fixed by spikes to stone sleepers, there is some difficulty in keeping the joint even and in its place, but it seems to be successfully obviated by using a saddle piece to receive the ends of the rails at the joint, an improvement which was introduced by Mr. Wilson,† on the Troon tram-road.

Tram-roads are much esteemed in Wales; and, in consequence of using them, they find it desirable to divide the pressure upon the rails as much as possible; hence, they have small carriages, and these lead to small wheels, so that the effect of a given power is not above half what it ought to be; and yet the enormous increase of rail-roads in Wales, renders it evident that they receive some benefit from adopting this system of conveyance.

* Transactions of the Society of Arts, &c., Vol. 25, p. 87; 1807.
† Dr. Brewster's Encyclop. art. RAIL-WAY.

Single Rail-Road, or Palmer's Rail-Way.

The rail-road invented by Mr. Palmer, is of a novel and ingenious kind. The carriage is drawn upon a single rail, the surface of which is raised about 3 feet above the level of the ground, and it is supported by pillars placed at equal distances, the average distance apart being about 9 feet. The carriage consists of two receptacles or boxes suspended one on each side of the rail by an iron frame, having two wheels of about 30 inches diameter. The rims of the wheels are concave, and fit to the convex surface of the rail; and the centre of gravity of the carriage, whether loaded or empty, is so far below the upper edge of the rail, that the receptacles hang in equilibrium; and will bear a considerable inequality of load without inconvenience, owing to the change of fulcrum from the breadth of the rail, which is about 4 inches. The rail is also made capable of adjustment, so that it may be kept straight and even.

The advantages of this arrangement consist in its being more free from lateral friction than even the edge rails; and, the rail being raised higher above the ground, it is much less liable to be covered with dust or any extraneous matters likely to affect the motion of the carriages. Also, where the surface of a country undulates considerably, a rail-way of this kind may be made without cutting to level the surface, except so far as is necessary to make a track that a horse can travel in.

When horses are employed, a track rope is required, which enables them to draw without material alteration of the angle of draught, while the weight of the rope serves as a spring to regulate the variable exertions of the horse.*

We expect, that this single rail-road will be found by far superior to any other for the conveyance of the mails and those light carriages of which speed is the principal object; because, we are satisfied, that a road for such carriages must be raised so as to be free from the continual interruption and crossings of an ordinary rail-way. A carriage moving at a greater rate than about 6 miles per hour, on a rail-way, must be raised so as to remove the possibility of overrunning people, or of dashing against other vehicles. Carriages running smoothly and rapidly with a small moving power, cannot be checked suddenly; and they admit of no change of direction. But were a rail-way elevated 10 feet above the common roads, these accidents could not take place, except through neglect; the passengers would not be raised to a much greater height than the top of a common coach, and in a suspended carriage, which could not possibly overturn. A road of this kind would be more free from interruption than any other; and a velocity sufficient for any useful purpose may be obtained at a small expense of power,

* See "Palmer's description of a Rail-way on a New Principle," where a full detail of the nature of this invention is given; illustrated by plates, with some very judicious remarks on rail-ways of other kinds, and a set of comparative experiments.

in a mode pointed out in the fourth chapter. Undoubtedly, a carriage might be suspended from between 2 rails raised at any height above the ground; and there would be some convenience in this arrangement, but it would be much more expensive, for the rails must be made firm and equidistant. As to the circumstance of the single rail dividing the carriage into two parts, that would most likely be esteemed a recommendation.

CHAPTER III.

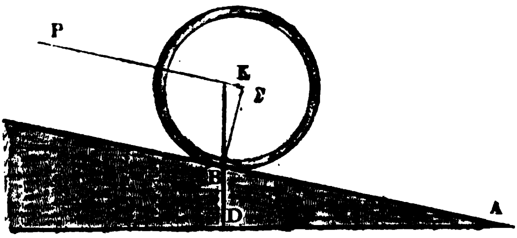
Of the force required to produce a given Effect on Rail-Roads—The Resistance from the Weight of Wheels, with Experiments—The Resistance at the Rails—The Resistance at the Axes of Carriages, with Experiments—Of Accelerated Motion on Rail-Roads—Ratio of friction to the Pressure—Proportions of Loco-motive Engines for plain Rail-Roads—Inclination for a Descending Trade—Proportions for Loco-motive Engines for Rails with Racks—Of the motion of Carriages on Rail-Ways—General Remarks.

THERE are so many circumstances that affect the motion of carriages on rail-roads, that, in the investigation of the subject, it will be necessary to divide it into parts, treating only of the most important.—1st, Considering the resistance arising from the weight of the wheels; 2dly, the resistance at the surface of the rail; 3dly, the resistance at the axis; with a comparison of each species of resistance and the practical maxims arising therefrom.

Of the Resistance from the Weight of the Wheels.

If a wheel be retained at rest on an inclined plane, by a force P, acting in the direction P C, it has been proved by writers on mechanics that the

weight of the wheel is to the force that retains it, as A B is to B D.



But a greater force than is determined by this proportion is necessary to roll the wheel up the plane with a uniform velocity; even on the supposition that the plane is perfectly hard and smooth. For let the moving force be attached to the centre of the wheel, then its velocity must be the same as that of the wheel's centre; but the quantities of motion in the wheel and the moving power must be equal; and since every point in the wheel, excepting the centre, describes a longer line, and consequently moves with a greater velocity than the power, therefore, an excess of moving force is required; and the quantity of excess we will now proceed to estimate.

Every point in the circumference of a wheel describes a curve, called a cycloid; and assuming that the lengths of the curves described by the intermediate points between the circumference and the centre, decrease in length in proportion to their distance from the circumference, the length of a cycloid being 4 times the diameter of the generating

circle, the mean velocity of the matter in the wheel, supposing it to be a solid cylinder, will be $\frac{4+3\cdot1416}{2} = 3\cdot57$, the velocity of the axis being $3\cdot1416$; hence, the power to keep the wheel in motion, is to the power to keep the same quantity of matter collected at the axis in motion, as $1\cdot137:1$ or a little more than one-eighth greater. In wheels a greater portion of matter is disposed nearer to the circumference; but, following the same mode of estimation, it does not appear that more than one-fifth of the weight of the wheels need in any case be added to give the equivalent mass which may be estimated as collected at the centre of the wheel.

The same conclusions apply so wheels moved on a horizontal road, and to any size of wheels; and the theory of rollers and roller wheels, involves the same considerations.

Expt. I.—We were now desirous of ascertaining by experiment, the force necessary to roll cast-iron wheels on a level rail-way with wrought-iron rails. For this purpose the wheels were put on an axis which had a barrel or roller 1·2 inches in diameter fixed on it, at the middle of its length. A fine flexible thread was wound round this roller, and passing over a pulley, it was drawn parallel to the rails by a weight at its extremity. The weight of a pair of 4-inch wheels and the axis, was 53 oz., and these rolled freely along the rails with a weight of 192 grains, the friction of the pulley having been ascertained by experiment and allowed for; and this force is equivalent to 250 grains, acting at the level

of the axis; or the moving force acting at the level of the axis was $\frac{1}{93}$ of the weight.*

Expt. II.—The weight of a pair of 8-inch wheels and the axle, was 119 oz., and rolled freely with a weight of 250 grains, when the friction of the pulley was allowed for, which is equivalent to 288 grains applied at the axis; or the moving force acting at the level of the axis was $\frac{1}{181}$ of the weight.

Hence, the ratio of the moving force to the weight of the wheel, is inversely proportional to the diameter of the wheel; for the diameters of the wheels are as two to one, and $\frac{1}{93}$ is to $\frac{1}{181}$, very nearly as two to one.

It appears from these experiments that the retarding effect of large wheels will not materially affect the motion of a carriage; and further, that we may consider the weight of the wheels as part of the load resting on the axles, which, while it greatly simplifies all inquiries concerning the movement of carriages, does not lead to an error worthy of notice in practice.

The Resistance at the Surfaces of the Rails.

It often happens, that a great part of the resistance at the rails arises from the lateral rubbing of

* In making these experiments we were reminded of the similarity of the apparatus to that which Paconius invented for moving the base of the collossal statue of Apollo from the quarry. (See Vitruvius, lib. X. cap. VI.) If Paconius had a rail-way, he would have had no difficulty in making his machine keep a proper direction.

the guides of the wheels; therefore, it is desirable to give the wheels a tendency to keep in their path with as little assistance from the guides as possible.

For edge-rail carriages this may be accomplished by making the rims of the wheels slightly conical, or rather curved, as shown in fig. 24; the carriage will then return of itself to its proper position on the rails, if it be disturbed from it by any irregularity.

In the tram-roads the rail might have a shape similar to the rim-wheel of edge-rails, which would give the wheels a tendency to keep clear of the guides; as when the wheels do rub against them the resistance is very much increased.

In Palmer's rail-way there is scarcely any lateral rubbing. The form he proposes for the upper edge of the rail, is a flat segment of a circle, the wheel concave and nearly of the same curvature; and this appears to us to be the best form that could be chosen for avoiding friction.

Another species of resistance is occasioned by extraneous matters on the rails, and from unevenness at the joints. Sometimes these will have the same effect on the motion of the carriage as rising over an obstruction; and in this case large wheels have the advantage over small ones.

If R be the radius of a wheel, and x the height of the obstruction, P the moving power, and W the weight of the load on the axle, then $R - x$ will be the leverage the power acts with to raise the wheel over the obstacle, and $\sqrt{2Rx - x^2}$ will be equal to the leverage by which the load acts to resist the effort of the power, and, therefore, $\frac{W\sqrt{2Rx - x^2}}{R - x} = P$.

Whence it appears, that the power required to raise a wheel over an obstacle of a given height, is nearly inversely proportional to the square root of the radius of the wheel; or a wheel of 4 feet diameter would be moved over an obstacle with half the power necessary to move a wheel of 1 foot diameter over the same obstacle.

When the wheels and the rails they move upon, are so proportioned that the stress does not cause a permanent change in the surfaces of either of them, then the resistance arising from the depression of the surfaces as they come into contact, will be almost wholly counterbalanced by the spring of the surfaces which are quitting one another; and a very small proportion of power will be lost. But where a permanent alteration of form takes place, or where dust or other matter, which crushes under the wheels, is on the rails, the resistance at the rail becomes considerable.

We may in either of these cases, on account of the smallness of x, reduce the preceding equation to $\frac{W\sqrt{2Rx}}{R}=P$. But x must be directly as W, and inversely as the radius nearly; hence, $x : \frac{W}{R}$; and we have $\frac{W\sqrt{2W}}{R} : P$, or $\frac{W^{\frac{3}{2}}}{R} : P$.

It appears then, that when there is a resistance at the surface of the rail, from the causes above noticed, it increases in a more rapid ratio than the weight increases; viz. as the square root of the cube of the weight; and therefore, there being almost invariably such resistance on tram-rails, we see the propriety of

the practical maxim of dividing the pressure as much as possible on such rails. But large wheels have the advantage in this case also; the power necessary to overcome the resistance being inversely as the radius of the wheel.

The resistance from dust is greater than would be expected; Mr. Palmer made an experiment to ascertain its effect on the Cheltenham tram-road, from whence it appears that it required $19\frac{1}{2}$ per cent. more power to draw the same carriages when the rails were slightly covered with dust, than when they were swept clean.*

On edge rail-roads dust and dirt cannot so easily accumulate, but when it does accumulate on rails where waggons with small wheels are used, its retarding effect is so great as to induce the managers of railways to have water carried before each train of carriages to sprinkle and wash the rails. Mr. Palmer remarks that this is done on the rail-way of the Penrhyn slate-quarries.† In other edge rail-ways, where the wheels are larger and the rails further apart, no such expedient is necessary.

It will be obvious that whatever be the amount of the resistance at the rails, it is of such a nature that it is difficult to reduce it to calculation; it depends much on the manner in which the rail-way is executed; and not a little on the state it is kept in. Our object has therefore been to shew only the circumstances which operate in reducing the quantity of this resistance.

* Description of a Rail-way, &c. p. 16. † Ibid. p. 17.

Resistance at the Axes of Carriages.

We have reserved to the last place that part of the resistance which consumes the chief part of the moving power on rail-ways. It is a subject which we cannot treat in a proper manner without the aid of both experiment and mathematical reasoning; but we propose to group our mathematical inquiries in distinct paragraphs, so that the general reader may pass the algebraical details with no further interruption than turning over the pages which contain them.

The pressure on the rubbing parts at the axis of a carriage is proportional to the weight of the body of the carriage and its load added to the stress of the power which moves it; the pressure being in the direction of the resultant of these forces. But the stress producing friction at the axis may be considered to be in a vertical direction, and equal to the weight of the carriage and its load, as the omission of that part of the power which overcomes the friction will cause no sensible error in practical cases.*

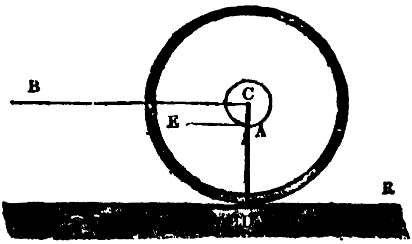
It is found by experiment that the friction of such bodies as are used for axes and their bearings, or bushes, is nearly proportional to the pressure in similar circumstances.

The pressure on the rails will always be greater than the pressure on the axis, by the stress from the

* Those who wish to enter more minutely into this question may find an example of a similar inquiry in Poisson's Traité de Mecanique, tome I. art. 130.

weight of the wheels; therefore, if the rails be only of the same smoothness as the surfaces at the axis, the wheel will not slide on the rails.

But the centre of motion is at C, the centre of the axis: and, let C B be the direction of the power, and E A the direction of the resistance from friction at the surface of the axis; the wheel being retained from sliding on the rail by the friction at D.



Now, conceive the power to move the wheel forward, and it will be obvious that the friction at D acts with a leverage D C, to turn the wheel on its axis; while the friction of the axis at A acts with only the leverage A C, the radius of the axle, to resist the effort of the moving power. Hence it is clear that, as far as the friction of the axle is concerned, if you double the radius of the wheel you reduce the power necessary to move the carriage, one-half, and so of other proportions; for the same axle will carry the same load, whatever size the wheels may be made.

This truth has been repeatedly published in this country, and yet it is singular that it has been overlooked by many of the writers on wheel carriages,

even by those who have made experiments; indeed, in the description of their experiments there is scarcely an instance of the ratio of the diameter of the wheel to that of the axis being given.

But, however satisfactory it is to arrive at an useful truth by reasoning, it is still more so to confirm it by experiment. For this purpose we had a small carriage made with two sets of wheels; one set double the diameter of the other. We used revolving axes of iron, working in brass bearings, so that, in changing the wheels, no change was made in the rubbing surfaces. The wheels are of cast iron, the rims turned, and the diameter of the small wheels is 4 inches, that of the large wheels 8 inches, and the diameter of the axes 0·55 inches. The rail-way is 12 feet long, formed of two pieces of bar iron, on edge, grooved into two pieces of deal $4\frac{1}{2}$ inches deep, and framed together to the proper width for the wheels to move upon the iron rails. The iron rails were filed straight and smooth on the upper edges; and we thus had a rail-way which we could place level, or at any degree of inclination. The following experiments were made with the rails level, and the axes oiled with olive oil.

Expt. III.—The 4-inch wheels were put to the carriage, and it was loaded till a weight of 2lbs. passing over a pulley, and drawing in a line parallel to the rails, produced a regularly accelerated motion on the rails, adjusted so that the first 3 feet were described in 9 seconds. The total weight of the carriage and load was $120\frac{1}{2}$lbs, and the friction of the pulley was ascertained to be ·057lbs., when

moving at the same velocity; hence, the moving force was 1·943lbs.; and $\frac{120\cdot5}{1\cdot943} = 62$; that is, the load was moved by $\frac{1}{62}$ part of its weight.

A moving force of 4lbs. was then put, and the load increased till the same space was described in the same time, as nearly as we could adjust it. The total weight of the carriage and load was now found to be 230·5lbs., and the moving force 3·886lbs.; consequently, the moving force was $\frac{1}{59\cdot4}$ of the weight.

From this experiment it appears that the resistance is not exactly proportional to the pressure.

Expt. IV.—The 4 inch wheels were removed, and the 8 inch ones put on the axes; and the pulley adjusted to render the line of traction parallel to the rails. The moving force of 2lbs. was applied, and the load increased till the first 3 feet were described in 9 seconds; it was then found to be 219·75lbs., including the carriage and wheels as before; consequently, $\frac{219\cdot75}{1\cdot943} = 113$ nearly; or the load was moved by $\frac{1}{113}$ of its weight.

This result does not exactly agree with the ratio of the diameters of the wheels, as it differs about $\frac{1}{10}$ when we take the case where the pressure was 120·5lbs., and $\frac{1}{20}$ when we take that where the pressure was 230·5lbs.; but whether this discrepancy arises from the resistance at the circumference, or from the friction at the axis, remains for us to determine.

When the load was increased till a moving force

of 3lbs. generated the same velocity in the same time, the total weight of the carriage and load was found to be 320lbs., from whence we found the moving force to be $\frac{1}{110}$ part of the load.

In this case, therefore, it also appears, that at least some part of the resistance increases in a more rapid ratio than the pressure.

It appears that a load of 230½lbs. was drawn by a weight of 4lbs., with 4 inch wheels; and a load of 219¾lbs, was drawn by a weight of 2lbs., with 8 inch wheels; and as the experiments were repeated frequently with as little variation as could be expected where the coincidence of the beat of a pendulum and the stroke of the carriage against a slight stop at the end of the first 3 feet were to be adjusted, we think that it may for rail-roads be assumed that the power, in the same circumstances as to axes and pressure, is inversely proportional to the diameter of the wheels.

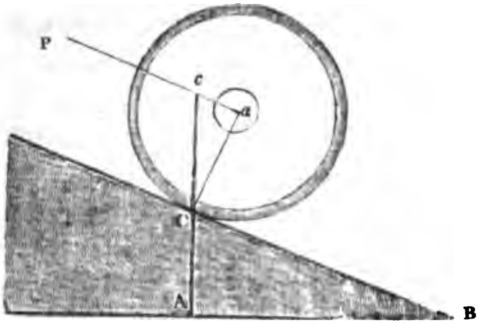
Resuming our inquiry in a more general form, let it be supposed that the power acts in a direction parallel to the rails on which the wheels move, and level with the axis; that is, let A B be a horizontal line; C B, the inclination of the rails; and P c, the direction of the moving power.

Put P = the moving power; W = the weight of the carriage and its load; F = the resistance from friction at the axle; and i = A B C, the angle of inclination.

Then, P — F = the part of the power employed in causing the carriage to ascend the plane, and as $c\,C : c\,a :: W : P - F$; but the triangles a C c and

A B C are similar; therefore, C B : A C : : W : P — F, or because $\frac{AC}{CB}$ = sin. i, we have

$$W \sin. i = P - F, \text{ and } W \sin. i + F = P.$$



But F is proportional to the pressure produced on the axis by these forces, and put R = the radius of the wheels, and r = the radius of the axles, and f = the friction, when the pressure is unity. The pressure on the axis is the resultant of the forces a C and a c, but a C = W cos. i; and a c = W sin. i; and the forces being at right angles, W $\sqrt{\cos.^2 i + \sin.^2 i}$ = the resultant; but this is equal to W, hence F = $\frac{W f r}{R}$; consequently, W $\left(\sin. i + \frac{f r}{R}\right)$ = P = the power to move a carriage up an inclined plane.

And W $\left(\sin. i - \frac{f r}{R}\right)$ = the tendency of the carriage to descend, which becomes o when sin. $i = \frac{f r}{R}$. Also, when sin. i is less than $\frac{f r}{R}$, we have

W $\left(\frac{f r}{R} - \sin. i\right)$ = P = the power to move a carriage down an inclined plane.

In the latter equation, when $\frac{f r}{R} = \sin. i$, we have $P = o$; or, the carriage will descend by its own weight. Hence, we have an easy experimental mode of arriving at the friction by adjusting the inclination of the rails till the carriage barely moves upon them; and then the friction is expressed by the sine of the plane's inclination.

Again, when the plane of the rails is level, $\sin. i = o$, and $W \frac{f r}{R} = P$, which gives the power equal to the resistance from friction; and our trials which have been described having been made in this manner, we shall have the means of comparing the two modes of experiment.

Expt. V.—The inclination of the rails was increased, till the carriage with the wheels of 8 inches diameter would descend with a continuous motion when loaded with 56lbs., the weight of the carriage and its wheels being $25\frac{3}{4}$lbs. The motion was perceptibly slower when 86lbs. more were added, but as regular as before; and when the whole load was taken off, the carriage ran very freely, but at a rate not exceeding an average velocity of one foot per second, a space of 9 feet being described in from 9 to 10 seconds. The inclination of the plane was found to be 1·76 inches in a distance of 12 feet, measured on the inclination. This gives $\frac{1}{68}$ of the weight, nearly, for the moving power. The motion was not so regularly accelerated as to allow of comparison by the laws of accelerated motion.

Expt. VI.—The wheels were removed from the carriage, and the 4 inch wheels put on; when the

rails had the same inclination as in the preceding experiment, the carriage would not move without additional force. The inclination was increased to 3·35 inches in 12 feet, measured on the rail, before the carriage would move with the same velocity as in the preceding trial. Consequently the force was equivalent to $\frac{1}{36}$ part of the weight. When 136lbs. were added to the weight of the carriage, the motion was slower. The weight of the carriage with the small wheels to it is $17\frac{1}{2}$lbs.

From these experiments it appears that the resistance does not decrease exactly one-half by doubling the size of the wheels, but the difference is not more than $\frac{1}{18}$ from that ratio. The resistance was much greater than in the experiments with the level rails, and chiefly from the guides.

Expt. VII.—The inclination was increased till the sine of the angle was ·039, and the time of descent was counted by the beat of a seconds pendulum, the space described being increased or diminished till the carriage struck against the block at the lower end of the rails at an even second. With the 4 inch wheels on, and a load of 40lbs., the carriage described 8·9 feet in 5 seconds; and 3·3 feet in 3 seconds; therefore the spaces described are very nearly as the squares of the times.

Expt. VIII.—With the 8 inch wheels, and a load of 40lbs. the carriage described 7·7 feet in 4 seconds.

To compare these experiments with the former ones, it is necessary to consider the formula for the

descent of bodies on inclined planes. The following table contains those most useful in this subject:*—

$$1.\ s = 16\tfrac{1}{12}\,p t^2 = \frac{v^2}{64\frac{1}{3}\,p}.$$

$$2.\ v = \frac{2\,s}{t} = \sqrt{64\tfrac{1}{3}\,p\,s}.$$

$$3.\ t = \frac{v}{63\frac{1}{6}\,p} = \sqrt{\frac{s}{16\frac{1}{12}\,p}}.$$

$$4.\ p = \frac{s}{16\frac{1}{12}\,t^2} = \frac{v}{32\frac{1}{6}\,t}.$$

Where s is the space described in feet, v the velocity acquired in feet per second, t the time in seconds, and p the force constantly acting on the body moved in parts of its weight. In applying these formulæ we shall omit the fractions, but we have retained them here in order that those who think it necessary may employ them.

We have shewn (p. 51) that W $\left(\sin.\ i - \frac{f\,r}{R}\right)$ is equal to the force which accelerates a carriage down an inclined plane, and therefore $p = \sin.\ i - \frac{f\,r}{R}$; whence, by formula 4, $\sin.\ i - \frac{f\,r}{R} = \frac{s}{16\,t^2}$, or $\sin.\ i. - \frac{s}{16\,t^2} = \frac{f\,r}{R}$.

In the preceding experiments $\sin.\ i = \cdot 039$, and in expt. vii. $s = 8\cdot 9$ feet, and $t = 5$ seconds; therefore $\cdot 039 - \frac{8\cdot 9}{16 \times 25} = \cdot 01666 = \frac{1}{60}$.

The second trial, where $s = 3\cdot 3$ feet, and $t = 3$ seconds, gives $\frac{f\,r}{R} = \cdot 016 = \frac{1}{62\cdot 5}$.

* See Dr. Hutton's Course of Mathematics, vol. ii. p. 331, 5th edition; or any work on Dynamics.

In expt. viii. $s = 7{\cdot}7$ feet, and $t = 4$ seconds; hence $\cdot 039 - \frac{7{\cdot}7}{16 \times 16} = \cdot 0089 = \frac{1}{112}$ nearly.

These experiments therefore afford results very near to those of experiments iii. and iv.; but the pressure was much less, and in this mode of making the experiment we could not conveniently increase it.

The ratio of the friction to the pressure, as deduced from these experiments, is the next subject to be considered: and since the diameter of the axis is $\cdot 55$, and that of the wheel 4 inches, when the whole resistance is $\frac{1}{60}$; we have $\frac{fr}{R} = \frac{f \times \cdot 55}{4} = \frac{1}{60}$, or $f = \frac{8}{1{\cdot}25} = 0{\cdot}1212$.

From the experiments with 8 inch wheels we have $\frac{f \times \cdot 55}{8} = \frac{1}{112}$, or $f = \frac{1}{7{\cdot}7} = 0{\cdot}12987$.

The mean between these is very nearly $\frac{1}{8}$, and this will be about the friction in practical cases, because we avoided that smoothness and accuracy of workmanship in preparing our model which could not be adhered to in machines for use.

Expt. IX.—To estimate the friction of the axis independent of the friction of the rail, the carriage was turned upside down upon a bench, with one pair of wheels projecting over its edge, and the other end of the carriage secured. A flat and flexible band was placed over each wheel, and to these bands a scale on each side was suspended. The addition of $\frac{1}{120}$th part to the weight, produced slow but regular motion with a pressure of 60lbs. and with a pressure of 120lbs.; and though there was a sensible variation in the velocity of the mo-

tion with the greater pressure, it was not so great as to be worthy of regard in practice. If we make no allowance for the stiffness of the bands, we have $f = \frac{8}{\cdot 55 \times 121} = \frac{1}{8\cdot 32}$.

It is clear from this trial that the resistance at the rails is inconsiderable, when they are clean, smooth, and even; hence, in investigations relating to the motion of rail-way carriages, we may confine our attention to the resistance at the axis.

Proportions of Loco-motive Engines for plain Rail-Roads.

When a loco-motive engine is employed to draw a train of waggons on a rail-way without cogs, the weight of the engine must be sufficient to produce at least as much friction on the surface of the rails, as is equal to the power necessary to move the train; for if the friction were less, the wheels would move round without advancing the carriage.

Let E be the weight of the engine carriage, and f' the friction when the pressure is unity; also let i be the angle of inclination.

According to the principles of mechanics, E. cos. i is equal to the pressure on the plane, and $E f' \cos. i$ = the friction.

Let the trade be a descending one, and the whole weight of the train of waggons and their loads = W, then by the equation (p. 51) $W\left(\frac{f r}{R} - \sin. i\right)$ = the power to move them, consequently, we must have

$$E f' \cos. i = W\left(\frac{f r}{R} - \sin. i\right);$$

$$\text{or, } \frac{E}{W} f' \cos. i = \frac{f r}{R} - \sin. i.$$

But in such small angles the cosine is not sensibly less than the radius, and therefore, practically,

$$\frac{f r}{\mathrm{R}} - \frac{\mathrm{E}}{\mathrm{W}} f' = \sin. i = \text{the sine of inclination};$$

$$\frac{\mathrm{E} f' \cos. i}{\frac{f r}{\mathrm{R}} - \sin. i} = \mathrm{W} = \text{the weight of the train of waggons.}$$

and, $\frac{\mathrm{W}}{f' \cos. i}\left(\frac{f r}{\mathrm{R}} - \sin. i\right) = \mathrm{E}$, the weight of the engine carriage.

When the rail-way is level, then $\cos. i = 1$, and $\sin. i = o$, whence $\frac{\mathrm{E} f' \mathrm{R}}{f r} = \mathrm{W}$; and $\frac{\mathrm{W} f r}{f' \mathrm{R}} = \mathrm{E}$.

It was now desirable to determine the value of f' by experiment, and which was done in this manner.

Expt. X.—The wheels of our carriage were fixed so that they could not turn; and the inclination of the rail-way was increased till the carriage would barely slide on the rims of its wheels. The tangent of inclination was then found to be $0{\cdot}165 = \frac{1}{6{\cdot}06}$; or the friction was very nearly $\frac{1}{6}$ of the pressure, cast iron sliding on wrought iron, and both rather smooth with wear. But for a case of this kind we should estimate the friction at a less proportion, say not exceeding $\frac{1}{12}$, for the surfaces become glazed and slippery by use. With this datum, and making the relation of the friction to the pressure at the axis $\frac{1}{8}$, we shall have

$$\frac{r}{8 \mathrm{R}} - \frac{\mathrm{E}}{12 \mathrm{W}} = \text{the sine of the inclination of the rails};$$

$$\frac{\frac{1}{12} \mathrm{E} \cos. i}{\frac{r}{8 \mathrm{R}} - \sin. i} = \mathrm{W}, \text{ the weight of the train of loaded}$$

waggons, and, $\frac{12 \mathrm{W}}{\cos. i}\left(\frac{r}{8 \mathrm{R}} - \sin i\right) = \mathrm{E}$, the weight of the engine carriage.

Example.—Let the weight of an engine carriage be 8 tons, and the weight of a train of waggons 98 tons, and the diameter of the waggon axles 3 inches, and the diameter of the waggon wheels 36 inches; then $\frac{r}{8R} - \frac{E}{12W} = \frac{3}{8 \times 36} - \frac{8}{12 \times 98} = \frac{1}{277}$; and if the descent be *less* than this, the wheels will turn rather than move the waggons.

If the waggons are to be drawn up an inclined plane, the formula will become

$$\frac{E}{12W} - \frac{r}{8R} = \text{the sine of inclination};$$

$$\frac{\frac{1}{12} E \cos. i}{\frac{r}{8R} + \sin. i} = W; \text{ and } \frac{12W}{\cos. i}\left(\frac{r}{8R} + \sin. i\right) = E.$$

Example.—Suppose the empty waggons of the preceding example to be drawn up a rail-way, their weight being 26 tons; then $\frac{8}{12 \times 26} - \frac{2}{8 \times 36} = \frac{1}{66}$.

From these examples it is obvious that a considerable degree of inclination is favourable for the action of loco-motive engines, in a descending trade; but the best inclination for a descending trade is that which renders an equal power applicable in either direction, and the weight of the engine must be adapted to conduct the ascending trade; for it will then be always equivalent to the descending one.

Let there be a descending trade, of which the weight, including the weight of the carriages, is W; and an ascending trade, of which the weight, including the carriages, is n W. Then, in order that the trade may be conducted in either direction by the same power, we must have, (from page 51),

$$W\left(\frac{fr}{R} - \sin. i\right) = nW\left(\frac{fr}{R} + \sin. i\right);$$

$$\text{or, } \frac{fr}{R} - \sin. i = \frac{nfr}{R} + n \sin. i;$$

$$\text{whence, } \frac{fr(1-n)}{R(1+n)} = \sin. i.$$

If the carriages are not to be returned, then we should have $n = o$, and $\frac{fr}{R} = \sin. i$.

And when $n = 1$, or the trade is equal in both directions, $\sin. i = o$, as it ought to be, indicating that the road should be level.

The same formulæ apply to inclined planes where the descending loaded carriages are to draw up light ones.

When the empty carriages alone have to be returned, then nW must be equal to the weight of the carriages, and the most usual proportion of the weight of the carriage to that of the load being as $1 : 4$, we have $n = \cdot 25$; and f being $\frac{1}{8}$, we have $\frac{\cdot 6\, r}{8\, R} = \sin. i = \frac{\cdot 3\, r}{4\, R}$.

If the diameter of the axis be 3 inches, and that of the wheel 36 inches, then $\frac{r}{R} = \frac{3}{36} = \frac{1}{12}$; consequently $\frac{\cdot 3\, r}{4\, R} = \frac{1}{160} = \cdot 00625$.

Proportions for Loco-motive Engines working in Racks.

We now have to consider the weight of an engine when it works wheels in racks. The correct form for the teeth for a rack of this kind will be the involute of a circle, and a practical mode of describing such teeth is given in Buchanan's Essays on Mill-Work, sec. ed. vol. i. p. 86. Assuming that the

teeth are described in that manner, the surfaces of the teeth in contact will be inclined to the direction of the upper edge of the rails in an angle of which the cosine is equal to half the pitch of the teeth, and its radius the radius of the wheel. Let this angle be denoted by a, and make i the angle of the inclination of the rails of the rail-way, E the weight of the engine, f' the friction when the pressure is unity, and P the power necessary to move the train of waggons.

Then $E \cos. i =$ the pressure of the engine in a direction perpendicular to the rails; hence

$$E \cos. i\,(f' \cos. a + \sin. a) =$$

the force which retains the engine in the teeth of the rack; and $P(\cos. a - f' \sin. a) =$ the force tending to draw the teeth out of the rack: therefore

$$E \cos. i\,(f' \cos. a + \sin. a) = P(\cos. a - f' \sin. a)$$

when these forces are in equilibrium.

From this equation we find

$\frac{P}{\cos. i}\left(\frac{\cos. a - f' \sin. a}{f' \cos. a + \sin. a}\right) = E$, the weight of the engine,

and $\frac{P - E f' \cos. i}{P f' + E \cos. i} = \tan. a.$

Where it is obvious that if $E f' \cos. i$ becomes equal to P, the tan. a becomes o; shewing that the friction of the rails alone is equal to prevent the engine carriage wheels from turning. But whenever the quantity $E f' \cos. i$ is less than P, a rack will be necessary; and with a wheel, of which half the pitch is to the radius as cos. a is to unity. This therefore determines the size of the wheel, for the pitch is determined by the strength of the teeth.*

* On the Strength of Teeth for Wheels, Racks, &c. see Tredgold on the Strength of Iron, art. 121, 2d edition.

Of the Motion of Carriages on Rail-Ways.

When a carriage is moved by a horse, he has the power of accommodating his force to circumstances, and in moving one by a mechanical agent it is necessary to provide a similar power of varying its force. This advantage of being able to vary the force is particularly felt in starting, or in stopping a train of waggons. The power which we have denoted by P in the preceding inquiries is that which is only just equivalent to keep the carriages in motion, at any velocity; and therefore an additional force p is necessary to generate the velocity, or to destroy it, as occasion requires. Then $P + p$ will be the whole force of the agent; and where it is a locomotive one it will be found desirable to have $p = P$, or its extreme power double its ordinary power; but in other cases this will not be necessary.

If the time of generating the velocity at which the carriages are to move be required, then p being the accelerative force in parts of the weight, v the velocity to be generated in feet per second, and t the time in seconds, we have by formula 3 (p. 54),

$$t = \frac{v}{32\,p}.$$

Example.—Suppose a carriage is to move at the rate of 6 feet per second; the excess of force being equivalent to $\frac{1}{200}$ part of its weight.

Here the time of generating the velocity will be $\frac{v}{32\,p} = \frac{6 \times 200}{32} = 37\frac{1}{2}$ seconds.

If the space the carriage will have to move

through to acquire the velocity be desired; the solution will be obtained by formula 1 (p. 54), s being the space in feet.

$$s = \frac{v^2}{64\ p}.$$

Example.—If a carriage be to move at the rate of 6 feet per second, which a little exceeds 4 miles per hour, what space must it move over to acquire that velocity, the excess of the engine's force being $\frac{1}{200}$ part of the weight of the load moved?

In this case $\frac{v^2}{64\ p} = \frac{36 \times 200}{64} = 112\frac{1}{2}$ feet.

This also shews the distance the carriage would move before its velocity would be destroyed. If we substitute for $\frac{1}{200}$ the ratio $\frac{1}{25}$ which is about the resistance of a common road, we find the space only 14 feet. Hence will be perceived the difficulty of preventing accidents from obstructions on rail-ways, for carriages moving with much velocity on smooth surfaces cannot be suddenly stopped.

General Remarks.—We have considered the friction to be $\frac{1}{8}$th of the pressure, at the same time that we are fully aware that it may be greatly reduced by good workmanship, and the application of proper kinds of grease to the moving parts. A carriage *selected* and *trimmed* for the purpose of experiment will never afford a fair measure of the average resistance on a rail-way, and we know of no other measure that is of any use in practice. Therefore, in taking a proportion from experience by which the power of engines, the load for horses, and the force of regulators could be measured, it was far from

desirable to be guided by the minimum resistance. The use of these inquiries in estimating the expense of conveyance on rail-roads may also be important; but, as in the other cases, an average, and not a minimum of resistance, must be the basis of the calculation.

In the recent works on rail-roads the friction has been estimated at the smallest possible quantity, but having reduced the question to the simple ratio of the friction to the pressure, it is easy to compare the result with other experiments.* The works we allude to have received considerable attention, and therefore it is more necessary that the hopes they hold out should be investigated.

* See Dr. Young's Nat. Philosophy, Vol. II. p. 170; Dr. Brewster's Encyclop. Art. MECHANICS, p. 597; or his 3d Edition of Ferguson's Lectures, Vol. II. p. 164.

CHAPTER IV.

Of the Moving Powers for Rail-ways—Horse Power—Duration of Day's Work—Maximum of Useful Effect—Power of Horses at different Velocities—Loco-motive Engines, High Pressure, Danger of—Principles of High Pressure Steam Engines—Power of High Pressure Steam Engines—Coals consumed by High Pressure Engines—Maximum of Useful Effect in Steam Engines—Low Pressure Engines—Gas Engines for Carriages—Station Engines to move Endless Chains, compared with Loco-motive Engines—Power of Low Pressure Engines.

In the economy of rail-roads it is of the greatest importance to consider the nature and effect of the different species of power that are likely to be applied on them. We shall commence with that which is most simple in its application and certain in its effect; how long it may maintain this rank is questionable, but at present there is not a superior agent for producing motion on a rail-way.

Horse Power.

When the power of a horse is to be applied to move carriages on a rail-road, it is obvious that we should endeavour to apply it in such a manner as will afford the greatest quantity of useful effect, with

as much speed as can be obtained, without injury to the animal. Hence, we have two objects of inquiry; these are, the duration of a day's work, and the maximum of useful effect.

Duration of the Day's Work of a Horse.

The time assigned for the day's work of a horse is usually 8 hours; but it is certain, from experience, that some advantage is gained by shortening the hours of labour; and we have observed, that a horse is least injured by his labour when his day's work is performed in about 6 hours. When the same quantity of labour is performed in less than 6 hours, the over exertion in the time shews itself in stiffened joints; while the wearying effects of long-continued action become apparent, if the duration of the day's work be prolonged much beyond 8 hours.

Horses are also frequently hurt by injudicious driving; and especially by starting with too great a velocity at the commencement of the day's work; but, under the management of a good driver, a full day's work may be completed in 6 hours, with benefit to the health and vigour of the animal, and a considerable saving of time. The barbarous practice of working horses to death we hope will never be introduced on rail-roads; and, in order to arrive at the extreme limits to which the average power of a horse may be calculated upon, we have taken much pains; and wholly remodelled the principles of treating this important subject.

It is a self-evident fact, that the work of a day

cannot be done in an hour; but, where speedy conveyance is desirable, it becomes of use to determine what proportion of work should be done, if the time of labour be shortened. In conducting this inquiry, it was convenient to make the calculations for the greatest speed a horse can travel at when unloaded, to continue to do so day after day; for then, the half of this velocity is that which corresponds to the maximum of useful effect; which will be shewn in the course of this inquiry.

From the nature of forces* we have this formula for the velocity corresponding to any limited duration of labour:—

$$\frac{14 \cdot 7}{\sqrt{d}} = v = \text{the greatest speed in miles per hour,}$$

unloaded, when the duration of labour is d hours.

We have been in the practice of collecting observations on these points for some years, and the results agree very well with those of our observations.

* Let m be the force of the muscles which can be continued for a day, and w the weight of the animal; and s the space described in a given time; then, $v = \sqrt{\frac{64\, m\, s.}{w}}$ But the space described in a given time is inversely as the duration of the day's work, or $s : \frac{1}{d}$; hence, $v : \sqrt{\frac{64\, m}{w\, d}}$; now, if the velocity be 6 miles per hour when d is 6 hours, we have $v = \frac{14 \cdot 7}{\sqrt{d}}$.

The inquiry is confined to the cases where the action is similar; but it is possible to push it further, and to analyse some points respecting the power and velocity of animals, which are not commonly supposed to be within the scope of mathematical calculation.

The following tablet will represent the duration of labour and maximum velocity, unloaded:

Duration of labour.	1 hour.	2hrs.	3 hrs.	4 hrs.	5 hrs.	6 hrs.	7 hrs.	8 hrs.	10 hrs.
Maximum Velocity, unloaded, in miles per hour.	14·7m.	10·4m.	8·5m.	7·3m.	6·6m.	6m.	5·5m.	5·2m.	4·6m.

This, within the range here given, may be considered as very near the law of decrease of speed by increased duration of labour, when a horse moves on a level road, unloaded; and the force of muscular exertion is then about equivalent to a fourth part of the weight of the horse.

If the road be inclined, the velocity of ascent will be decreased in proportion to the sine of the inclination, and increased in descent in the same proportion.

These data being settled, the next step in our inquiry is, to ascertain the velocity which corresponds to the maximum of useful effect.

Maximum of Useful Effect.

The speed which corresponds to the maximum of useful effect, is of considerable importance, as the expense of horse power very much depends on it.

When a horse travels, unloaded, the greatest distance he can travel, so as to continue to do so day after day without injurious fatigue, is obviously the limit of velocity; but the work done must be nothing in this case. And it is also obvious, that when a horse travels at such a rate that the empty carriage

or waggon is equal to his power, the work done is nothing. On the other hand, the load may be so great that the horse can barely put it in motion, in which case, also, the useful effect is nothing; but between these limits of velocity and power there is a proportion, which affords the maximum quantity of useful effect, and therefore must be the most advantageous for the application of horse power on a railroad.

The velocity which corresponds to the maximum of useful effect, is half the extreme velocity of a horse when unloaded.* The extreme velocity of a good horse, unloaded, is not more than 6 miles per hour,

* Let V be the maximum velocity of a horse when unloaded, and m the constant muscular force which generates that velocity; w the resistance overcome when the horse is unloaded; and v, any other velocity. Then, $m\,v - w\,v =$ the power which is effective; but $m\,v = \mathrm{V}\,w$, or $\frac{m\,v}{\mathrm{V}} = w$; hence, $m\,v - \frac{m\,v^2}{\mathrm{V}} =$ the effective power, and it is to be a maximum.

The maximum has place when the fluxion of the variable quantity is o, or when $v - \frac{2\,v\,v}{\mathrm{V}} = o$, that is, when $\mathrm{V} = 2\,v$. Consequently, the velocity which corresponds to the maximum of useful effect, is half the greatest velocity of the horse when unloaded.

Let P v be the power of a horse, then

$$m\,v - \frac{m\,v^2}{\mathrm{V}} = m\,v\left(\frac{\mathrm{V} - v}{\mathrm{V}}\right) = \mathrm{P}\,v; \text{ and } m\left(\frac{\mathrm{V} - v}{\mathrm{V}}\right) = \mathrm{P}.$$

When $v = o$, $\mathrm{P} = m$; therefore m is always equal to the force which exactly balances a horse's power at rest; and when $v = \mathrm{V}$, $\mathrm{P} = o$, as it ought to be.

At the maximum $\frac{1}{2}\,m = \mathrm{P}$, and as m is a constant quantity, the force at the maximum will be a constant quantity, whatever number of hours may be fixed upon for the day's work. In a horse of average strength, $m = 250$ lbs.

when continued for six hours; and therefore, 3 miles per hour must be the velocity corresponding to the maximum effect, when the time of labour is 6 hours.

If the day's work were continued 8 hours, the extreme velocity would be reduced to 5 miles per hour, which gives $2\frac{1}{2}$ miles per hour for the velocity corresponding to the maximum of useful effect.

The rates for inferior horses will be less, but the difference should rather be made in power than in the rate of travelling.

Now, it has been found by a considerable range of experience, that the average power of a horse is 250 lbs.; hence, $\frac{250}{2}=125$ lbs. nearly; which, therefore, may be taken as the force of a horse moving at the rate of 3 miles per hour, for 6 hours of a day.

If the length of the day be 8 hours, the force of the horse is the same, but moving at the rate of $2\frac{1}{2}$ miles per hour, for 8 hours of a day.* The difference

* The measure of a horse power adopted by Messrs. Boulton and Watt, in calculating the power of their engines, was, that "a horse going at the rate of $2\frac{1}{2}$ miles per hour, raises a weight of 150 lbs., by a rope passing over a pulley," the day's work being 8 hours.—Robison's Mech. Phil. vol. ii. p. 145. Hence, $8 \times 2\frac{1}{2} \times 150 = 3000$ lbs. raised one mile for the day's work. The same measure of the power of a horse is taken by Mr. Palmer, in his "Description of a Rail-way," p. 28. This is very well established as an elementary expression for the horse power in estimating the effect of machinery, but it is much too high for the actual effect of an average horse. We have inserted the greatest stress on the traces that ought to be attempted in practice, which for the day of 8 hours, gives $8 \times 2\frac{1}{2} \times 125 = 2500$ lbs. raised one mile; and for the day of 6 hours 2250 lbs. raised one mile. To Mr. Bevan we are indebted for some observations made on the force of traction required to move canal

being only in the velocity, whatever difference is made in the length of the day's work.

The best division of the labour, for heavy carriages, would be, to divide the road into stages of 9 miles each, when the day's work is 6 hours; and to work the horses 3 hours, with an interval of 6 hours between that and the next 3 hours' labour. When the greatest quantity of goods is to be moved at the least expense of horse power, we have shewn that the maximum velocity will be 3 miles per hour; and whatever greater degree of velocity is obtained, must be at an additional expense. It will be useful to shew the addition of expense, from a variation of velocity from the maximum of useful effect; and also, from shortening the duration of the day's labour.

First, let the hours of labour be the same, viz. 6 hours per day, the maximum of useful effect is then 125 lbs., moving at the rate of 3 miles per hour; and let the expense of carriage in that case be 1.*

boats on the Grand Junction Canal, (see Chap. VIII.), and he found the force of traction 80 lbs., and the space travelled in a day 26 miles; hence, it is only equivalent to $26 \times 80 = 2080$ lbs. raised one mile for the day's work; the rate of travelling is 2·45 miles per hour. This is less, considerably, than our formula would give for this case, for it makes the day's work 2,900 lbs. raised one mile; but the speed is extremely near to that calculated by our rule; and the line of traction on canals being oblique to the direction of the motion of the horse, makes some difference in his power.

* In a former note (p. 68,) we have shewn that $\frac{250\,v}{V}\left(V-v\right) =$ the power of a horse; and supposing the force, at the maximum of useful effect, to be unity, we have $\frac{2\,v}{V}\left(V-v\right) =$ the power; the

Miles per hour.		Proportional expense.		Moving force.
2	......	$1\frac{1}{8}$ or 1·125	......	166 lbs.
3	......	1	......	125 —
$3\frac{1}{2}$	......	$1\frac{1}{35}$ or 1·0285	......	104 —
4	......	$1\frac{1}{8}$ or 1·125	......	83 —
$4\frac{1}{2}$	......	$1\frac{1}{3}$ or 1·333	.....	$62\frac{1}{2}$ —
5	......	$1\frac{4}{5}$ or 1·8	......	$41\frac{2}{3}$ —
$5\frac{1}{8}$	......	2	......	$36\frac{1}{2}$ —

That is, the expense of conveying goods at 3 miles per hour, being 1; the expense at $4\frac{1}{2}$ miles per hour, will be $1\frac{1}{3}$; and so on, the expense being doubled when the speed is $5\frac{1}{8}$ miles per hour.*

If the hours of labour be shortened, taking the velocities which correspond to the greatest useful effect, the expense is inversely as the product of the velocity by the duration of the labour; making the expense for 6 hours, and 3 miles per hour, unity or 1.

expense being inversely as the power, therefore, the expense of conveying goods 3 miles at any velocity, v, will be as $\frac{1}{2} : \frac{V}{2v(V-v)}$ $:: 1 : \frac{3\,V}{2\,v\,(V-v)} = \frac{9}{v\,(6-v)}$ when $V = 6$.

If $v = 2$ miles per hour, then $\frac{9}{2\,(6-2)} = 1\frac{1}{8}$.

If $v = 4$ miles per hour, then $\frac{9}{4\,(6-4)} = 1\frac{1}{8}$. While the velocity being 3 miles per hour, the expense is only 1.

* In a series of Essays on Rail-roads, which were published in the Scotsman Newspaper, and since in a separate pamphlet, Professor Leslie's formula is used for estimating the force of traction. That formula appears to be made to fit certain observations which are not detailed, and is not founded on true principles.—See Leslie's Elements of Natural Phil. p. 252.

Duration of La[bour].	Miles per Hour.	Proportional Exp.	Miles per Hour.	Proportional Exp.
1 hour	7½	2·45	11	3·25
2 hrs.	5·2	1·73	7·8	2·3
3 —	4¼	1·41	6·4	1·87
4 —	3½	1·23	5.5	1·63
5 —	3¼	1·1	4·9	1·46
6 —	3	1	4½	1·333
7 —	2¾	·94	4⅓	1·25
8 —	2½	·90	3¾	1·2
10 —	2⅓	·74	3½	·985

In this table, the first column gives the duration of abour in each 24 hours; the second, the miles per hour, when the work done in the time is the greatest possible; the third column shews the expense of carriage, when that by an average horse working 6 hours per day, and travelling 3 miles per hour, is denoted by 1. In this case the road is supposed to be perfectly level, and the stress on the traces 125 lbs. The fourth column shews the velocity when the stress on the traces is only 62½ lbs. per horse; and the fifth column, the proportional expense of carriage.

We give these as the full values of an average horse power, in all the cases considered. On canals they find their advantage in travelling at about the velocity corresponding to the maximum of useful effect, to a day of 10 hours long, and continue their labour with little intermission throughout this long day, except while the boat is passing the locks. If they attempt to go at a quicker rate, the increase of resistance becomes very considerable, the resistance to motion in fluids increasing nearly as the square of the velocity. On the contrary, on rail-roads the

resistance remains nearly the same at all velocities; hence, speed will be one of the chief of their advantages. The table shews that, as soon as the speed exceeds $4\frac{1}{2}$ miles per hour, there is a decided advantage in shortening the duration of labour, in preference to reducing the quantity of draught. Experience, or rather a combination of circumstances, has led coach proprietors to the same result; but they have reasoned a step further, and found it more profitable to double the quantity of labour here assigned for the day's work of a horse, and to *wear* the horse out in 3 or 4 years. The difference between the interest that will return the excess of capital expended in the purchase of fresh horses, and the annual expense of keeping a greater number of them, is too great to allow the proprietor of 3 or 400 coach horses to hesitate about 130 of them in a year being sacrificed. It is a melancholy reflection to recollect, that there is at all times in this country several thousands of horses wearing down under excess of labour; may we hope that rail-roads will in some degree lessen the evil, and diminish the quantity of animal torture.

There does not appear to be any chance of rendering the wind of use, as a moving power on rail-roads; and, therefore, we may next proceed to inquire respecting the advantages of Steam, when applied as a moving power. Steam may be employed through the intervention of a fixed engine, or by an engine to move with the carriages. We have to consider the comparative value and uses of both these modes of application.

Loco-motive Engines.

A loco-motive engine is a steam engine placed on wheels in such a manner, that the force of the engine can be applied to impel these wheels, and by that means draw along a train of waggons. In some cases part of the wheels of the engine carriage have teeth, which work into racks cast on the rails of the road; but in other cases the wheels and rails are like the common waggon wheels and rails, and the friction of the wheels on the rails is the only resistance employed for the power of the engine to act against in drawing forward the train of waggons; sometimes a small degree of sliding takes place, which wears away the wheels of the engine carriage very rapidly, hence, the proper inclination and quantity of pressure to prevent sliding, have been considered both for plain rail and racks. See Chap. III. p. 56 and 59.

High-Pressure Engines.—In consequence of the small weight and the simplicity of the operation of high-pressure steam engines, they alone appear to have been used on rail-roads; they work at a pressure of from 30 to 50 lbs. on the square inch, above the pressure of the atmosphere; and as we have some objections to engines of this kind being used on a rail-way for general purposes, we shall briefly explain the grounds of these objections.—In the first place, the rules by which the strength of boilers are calculated are not at all accurate, and tend to make the calculator expect that they will bear a much greater pressure than it is possible they can

sustain. The ordinary method of proving boilers, by hydrostatic pressure, does not assist us in correcting the defect; for the boiler is not, by that means, proved under circumstances similar to those it is exposed to in use. Also, when the proof pressure exceeds a certain and well-known relation to the ultimate strength of the material, the boiler suffers an irreparable injury from the proof of it.

To produce high-pressure steam, a high degree of heat is necessary; and the action of this heat on the boiler is very unequal, producing an unknown strain from irregular expansion; the risk from this strain is much lessened by using a ductile metal for the boiler, but its nature and force is the same, or nearly so. The fire is also constantly impairing the strength of a boiler, by burning and destroying the matter it is composed of; and, as a more intense heat is necessary to produce steam through a thick boiler than through a thin one, the strong boiler must be subjected to more frequent examination.

But, even all these objections might be obviated, if we could rely on human prudence in the use of these engines: on a rail-road, where there is reason to expect competition, there must be a proportional risk of accident, for men will run the greatest hazards in such circumstances; and, where personal danger has no influence, the most ingenious means may be used to guard against a dangerous increase of pressure, and yet be rendered futile by the fertile thought of a man ambitious to be the swiftest on the line.

We have stated our objections, and will now pro-

ceed to consider the velocity, power, and the means by which the high pressure steam carriage may be improved.

In respect to velocity, it is limited only by the expense and risk of accident; but there is a velocity for a steam engine which gives a maximum of useful effect, as well as in horse power; and after having shewn the power of the engine, we will put this new deduction of science before the reader.

To increase the velocity, without departing from the simplicity of the movements of the engine, the radius of the wheels may be increased. But it is not desirable, for reasons we shall give a little further on, that the velocity of the steam piston should exceed 170 feet per minute, when the length of the crank is 12 inches, and then the piston will in that case describe 4 feet for each revolution of the wheel, or make $42\frac{1}{2}$ stokes per minute. The velocity of the carriage is to the velocity of the piston as the circumference of the wheel is to twice the diameter of the crank, consequently it is easily computed. 170 feet per minute is 1·93 miles per hour; and making c the radius of the crank, and R the radius of the wheel,

$$4\,c \;:\; 6.2832\,R :: 1{\cdot}93 : \frac{3{\cdot}03\,R}{c} =$$

velocity of carriage in miles per hour. Thus if the radius of the crank be 12 inches, and that of the wheel 19 inches, then $\frac{3{\cdot}03 \times 19}{12} = 4{\cdot}8$ miles per hour; and by enlarging the wheels any proposed degree of velocity may be obtained consistent with practice.

In employing high pressure engines there is a

considerable loss of fuel, not less than is equivalent to convert the whole of the water used by the engine into low pressure steam. At a colliery this is of little importance; but where coals are expensive, even a small loss of effect becomes a serious disadvantage in the maintenance of steam power.

Having had frequent occassion to consider the nature and power of steam, and having, by a careful comparison of our theory with practice, found that it embraces the most important points in question regarding steam power, we give our formula in this place, leaving the investigation till another opportunity offers itself to make it public.

If f be the force of steam in inches of mercury, and t the corresponding temperature; f' the resistance from the friction of the steam piston, and the uncondensed vapour in the cylinder, or the atmospheric pressure in high pressure engines, and n the bulk of the steam cylinder, when the bulk of the steam admitted at the pressure f is unity. Then the power of the steam generated from a cubic foot of water is

$$4873\ (459 + t) \times (1 - \frac{nf'}{f} + \text{hyper. log. } n).$$

When the steam does not act by expansion $n = 1$.

If the expanding force of the steam be employed, then the equation has a maximum, which must take place when (hy. log. n) $- \frac{nf'}{f}$ is a minimum, and it is easily shewn that this takes place when $n = \frac{f}{f'}$. Therefore when $\frac{f}{f'}$, is inserted for n, we have,

$4873\ (459 + t) \times$ (hy. log. $\frac{f}{f'}$ = the maximum

power of a cubic foot of water converted into steam. When $f = f'$, the hy. log. $\frac{f}{f'} = o$, and the power nothing, and when one less $\frac{f'}{f}$ is greater than the hyperbolic logarithm of $\frac{f}{f'}$, it is a disadvantage to work by expansion.

To calculate the quantity of fuel, let c be the quantity which converts a cubic foot of water into steam that will bear the pressure of the atmosphere, and let s be the specific heat of the steam, a the specific heat of the air and smoke which escape up the chimney, and w the fuel that will heat one cubic foot of water one degree; then

$$c + \overline{(t - 212^{\circ}) \times (a + s)\, w} =$$

the least quantity of fuel that will be required to produce steam of the force f and temperature t.

Taking as data* $c = 8{\cdot}4$lbs. of Newcastle coal, $w = {\cdot}0075$lbs. $s = {\cdot}847$, and $a = {\cdot}753$ we have

$$8{\cdot}4 + {\cdot}012\,(t - 212) =$$

the lbs. of coal to produce steam of the temperature t.

We shall now apply these formula to determine the power and expense of a high pressure engine. In so doing we may take 30 inches as the atmospheric pressure.† To determine the friction of the steam piston, and piston rod, we may assume, without material error, that the whole quantity of rubbing

* See Tredgold on Warming and Ventilating. Tables I. and II. p. 279 and 280, second edition.

† A mean of 20 years, deduced by Mr. Howard from the observations of the Royal Society, is 29·8655 inches for London; and a mean of Mr. Daniell's for 3 years is 29·881 inches. See Daniell's Meteorological Essays, p. 266.

surface is equal to the area of the cylinder; and we know that these surfaces cannot possibly be steam-tight, if they be pressed together with less force than the pressure of the steam; and as we do not know exactly what excess of pressure is necessary, suppose we assume that the surfaces are pressed in contact with double the force of the steam. As the friction is nearly proportional to the pressure, and in this case, about $\frac{1}{10}$ of that pressure, we shall have $\frac{2f}{10} = \frac{1}{5}f =$ the friction; that is, the friction of the steam piston is one-fifth of the pressure of the steam; to which $\frac{1}{20}f$ may be added for plus pressure in the boiler, making the loss $\frac{1}{4}f$.

But one side of the piston of a high pressure engine is acted on by the same pressure as that of the external atmosphere, hence $f' = \frac{1}{4}f + 30 =$ the resistance to the moving force f.

Therefore, when a high pressure engine is worked expansively, we have

$4873\ (459 + t) \times \left(\text{hy. log.}\ \frac{f}{\frac{1}{4}f+30}\right) =$ the mechanical power of a cubic foot of water converted into steam.

From this equation it is obvious, that there is no advantage gained by making a high pressure steam engine to work expansively, when the force of the steam is less than 60 inches of mercury, for then the hyperbolic logarithm is less than $1 - \frac{\frac{1}{4}f+30}{f}$.

When an engine does not employ the expansive power of steam, we have

$4873\ (459 + t) \times \left(1 - \frac{\frac{1}{4}f+30}{f}\right) =$ the mechanical

power of a cubic foot of water converted into steam.

Example.—Let the force of the steam be 120 inches of mercury; the corresponding temperature by Mr. Philip Taylor's Table * is 292·8°. Then

$$4873\ (459 + 292{\cdot}8)\ \times\ \left(1 - \frac{(\frac{1}{4} \times 120) + 30}{120}\right) =$$

1,830,000lbs. raised one foot high.

The quantity of coal is $8{\cdot}4 + {\cdot}012\ (292{\cdot}8 - 212) =$ 9·37lbs. of coal.

Now the horse power is 16,000,000lbs. raised one foot in a day of 8 hours; † hence if

1,830,000, : 9·37lbs. :: 16,000,000 : 82lbs.

Therefore, working with steam of 44½lbs., on the square inch on the piston, above the pressure of the atmosphere, 82lbs. of Newcastle coal ought to do the day's work of a horse.

But if the engine works expansively with the same force of steam, then

$$4873\ (459 + 292{\cdot}8 \times (\text{hy. log. } 2) = 2{,}540{,}000\text{lbs.}$$

raised one foot high by 9·37lbs. of coal; and consequently 59lbs. of coal ought to do the day's work of a horse.

In Table I. at the end of this work, the power of a cubic foot of water when converted into steam of different degrees of force is shewn, whether working expansively so as to produce the maximum of effect, or working at full power during the whole stroke,

* Philosophical Magazine, vol. 60, p. 452.

† $33{,}000 \times 60 \times 8 = 15{,}920{,}000$lbs. which is the usual horse power of steam engines; but our horse power is ¼th less. (See p. 69, and note.)

also the quantity of fuel consumed in each case. From this table it is easy to ascertain the quantity of coal equivalent to the day's work of a horse as in the preceding examples.

These results are however applicable to an engine at rest only; and in applying them to a loco-motive engine the power expended in moving the weight of the engine itself must be deducted in order to render them directly comparable with horse power. Therefore, supposing the lbs. of coal equivalent to the day's work of a horse to have been found by the preceding method, that quantity multiplied by the weight of the train of waggons drawn by the engine, and divided by that weight less the weight of the engine carriage, will give the number of pounds of coal which applied to a loco-motive engine, are equivalent to the day's work of a horse. Thus, let the train of waggons weigh 72 tons, and the engine carriage and apparatus 8 tons, and 82lbs., the quantity of coal that would do the day's work of a horse in a stationary engine; then $\frac{72 \times 82}{72-8} = \frac{72 \times 82}{64} = 92\frac{1}{4}$lbs. for the quantity for a loco-motive engine of the weight above specified.

The advocates for high pressure engines will perhaps think that this loss of effect will be made up for by employing the waste steam to heat water for the boiler; and it would be so, for by a well-proportioned apparatus for that purpose about 11lbs. of coal might be saved out of $92\frac{1}{4}$lbs. The best mode of effecting this would be to make the waste steam pass through pipes having a considerable quantity of

surface in the supply cistern, which ought to be on the steam carriage in all cases, and after quitting the pipes through the cistern it should pass through small metal pipes or trunks formed so as to present as much surface as possible to the air,* and the water condensed in these pipes should descend into the cistern: the steam which is not condensed in going through the pipes should go into the chimney to aid the draught.

But we consider, that whatever is saved in this manner will not be more than equivalent to the loss by the waste and loss of heat at the boiler, even when protected in the best manner, and managed with the utmost care. For there is a difficulty in getting surface for the heat to act on, and the draught must be much too weak for producing high pressure steam. We expect if these engines do get into more general use that an artificial blast will be found an advantage and be applied accordingly.

From the various causes of loss of effect the quantities we have given may be increased about 30 per cent, making the coals equivalent to the day's work of a horsc 124lbs. in the best loco-motive engines likely to be invented.

As to the engines on the Newcastle rail-roads, they at an average consume at least twice the last quantity to do the same work.

* The quantity of surface to condense a given quantity of water may be easily calculated by the rules in Tredgold's Principles of Warming Buildings, p. 61, 2d edition.

Maximum of Useful Effect in Steam Engines.

The next subject of inquiry is the maximum power as it depends on the structure of the engine, for each individual engine must have its rate corresponding to the maximum of effect. If the steam piston exceeded a certain velocity, if is obvious that the boiler would not be capable of affording the requisite quantity of steam; and the same thing would happen from the steam passages, were they smaller than in due proportion to the power of the boiler. But it will be evident, that the steam should be capable of following the piston at its extreme velocity, which of course determines one of the most important points in proportioning them from theoretical principles. The conditions, then, which limit the velocity of the piston are now to be considered; and these are the moving force and length of the stroke when the resistance is the friction of the piston only, and the steam at full action as it is intended to be in the average working state of the engine. The motion of the piston, under such circumstances, may be considered an accelerated one, and let w be the weight of the mass to which the piston gives the final velocity 2 V at the end of the stroke, P the effective pressure on the piston in lbs.; and l = the length of the stroke in feet. Then $60 \times 8 \sqrt{\frac{Pl}{w}} = 2\,V$, or $240 \sqrt{\frac{lP}{w}} = V$, the mean velocity of the piston in feet per minute.

But if the machine be properly arranged, the

weight of the mass, w, will regulate the velocity and render it an uniform velocity V after a certain time, and in order that this may be the case, we must have $w = P$, consequently, $240\sqrt{l} = V$. But we have shewn (note to p. 68) that v the velocity corresponding to the maximum of useful effect ought to be $\frac{1}{2}$ V; and therefore we have $120\sqrt{l} = v$, the best working velocity for an engine in feet per minute.

If an engine has a 2 feet stroke, then $v = 170$ feet per minute, and the number of strokes per minute $42\frac{1}{2}$.

By increasing the stroke to 3·4 feet we get a velocity of 220 feet per minute, with 32 strokes per minute.

If any variation be made from the maximum power the decrease of effect is the same as in horse power (see tables p. 71) but we have this advantage in an engine, it can be made for any velocity, by attending to the relative proportions of its parts; those of a horse we cannot alter.

The apertures for steam passages, the surface exposed to the fire, the magnitude of the fire-place, and the area of the chimney must all be proportioned so that the engine would work at twice its proper velocity.

Low pressure Loco-motive Engines.—The circumstances which are deemed unfavourable to the use of low pressure engines for steam carriages are the complexity of the apparratus, and the weight of water necessary for condensation; and the bulk occupied by the one and the immense quantity of the other render it quite improbable that they can ever be

employed with any degree of advantage. It will require not less than half a ton of water per hour for each horse power for condensation only; consequently there is no chance of applying a condensing engine in this manner; and it is useless to make further calculations respecting them.

Gas Engine for Carriages.—Lately a new method has been proposed for moving carriages, which has excited so much attention that we cannot omit some notice of it.

The power of this new engine is gained by burning gas in a cylinder so as to rarefy its contents in a very considerable degree; it is then cooled, and the difference between the pressure of the atmosphere and the elasticity of the air in the cylinder constitutes the moving power. It has been attempted to shew that the power results from the products of the combustion being condensed into less bulk than the combustibles occupied before, but this solution is inadequate to explain the effect produced.

The principle of its action may be easily illustrated by a simple experiment. Let a piece of paper, which inflames readily, be burnt under an inverted glass so as to fill its capacity with flame, and then immediately immerse the mouth of the glass in water. The consequence is that the hot air or flame is condensed by the water, and shrinks into a space of about one-third of the capacity of the glass, while the water rises and fills it till the contained air be of the same elasticity as the atmosphere.

Mr. Brown, the inventor of the gas machine, produces a similar effect by burning gas in a metallic

cylinder, and by means of the flame of gas, and an apparatus which is very ingenious, renders this well-known phenomenon a means of obtaining a considerable quantity of mechanical power. Whether this power be likely to be useful for loco-motive carriages or not, we now will proceed to examine.

To ascertain the degree of rarefaction (or of vacuum) in the cylinder, let x = the temperature of the flame, the original temperature of the air in the cylinder being 50 degrees. Then $\frac{450+x}{500}$ = the bulk of the expanded air;* and when the pressure of the atmosphere is 30 inches of mercury, we have

$1 : \frac{500}{450+x} :: 30 : 30\left(\frac{500}{450+x}\right)$ = the force of the air left in the cylinder when cooled to 50°; consequently $30\left(1-\frac{500}{450+x}\right)=\frac{30(x-50)}{450+x}$ = the force on the piston in inches of mercury, without reduction for friction or other causes of loss of effect. If the temperature of the flame be 1050 degrees, which is a temperature we think it would be easy to give it, then $\frac{30(1050-50)}{450+1050}=20$ inches of mercury for the force on the piston without reduction for friction, &c.

Our next inquiry is the expense of gas required to produce a given quantity of mechanical power. Let b express the cubic feet of gas that will heat a cubic foot of air one degree; then bx is the volume of gas that will heat a cubic foot of air x degrees; and $bx : 1 :: 1000 : \frac{1000}{bx}$ = the volume of air that

* Tredgold on Warming Buildings, &c. art. 220, 2d edition.

would be heated by 1000 feet of gas; consequently $\frac{1000 \times 30\,(x-50)}{b\,x\,(450+x)}$ = the mechanical power of 1000 feet of gas when not reduced for friction.

But this equation has a maximum, and making x variable, and its fluxion equal to zero, we have $x=208$ degrees, hence the greatest degree of mechanical power will be obtained when the temperature of the rarefied air is 208· degrees, and, calculating to this maximum power, we have very nearly $\frac{35}{b}$ = the mechanical power of 1000 feet of gas, not reduced for friction, in inches of mercury.

The weight of an inch of mercury one foot square being 70·7lbs., the lbs. raised one foot high, supposing there was no friction, would be $\frac{2474}{b}$ by 1000 cubic feet of gas.

The maximum temperature will be different when the proper reduction is made for friction, and the effect less, but it will be sufficient for our purpose to estimate the gross power.

If pure olefiant gas were used, we should have, from Mr. Dalton's experiments,* $b=\frac{1}{41040}$; which gives about 102 millions of pounds raised one foot for the mechanical power of 1000 cubic feet of gas not reduced for friction; and therefore 1000 cubic feet of oil gas would not do more than the work of 6 horses in an engine, even if the gas worked by an engine entirely devoid of friction, and consequently it must be much too expensive for any rail-road conveyance.

If coal gas be employed, its effect must be less

* Dr. Thomson's System of Chemistry, vol. i. p. 148.

than that of pure carburetted hydrogen, and for carburetted hydrogen $b = \frac{1}{22800}$;* from which we find its mechanical power 56 millions of pounds raised one foot high by 1000 cubic feet of gas working in an engine without friction; and this not being more than the useful effect of 3¼ horses, it is pretty evident that the gas engine must be much too expensive for any case where the work can be done with horses. In a machine of this kind, we cannot allow less for the loss by friction, and waste of heat, &c. than one-third, which makes the power of 1000 feet of oil gas equivalent only to that of 4 horses, and 1000 feet of coal gas not quite equivalent to 2½ horses. The engines are more complex than high pressure steam engines, and in the event of using them for loco-motive engines, the gas must be compressed into a space of about $\frac{1}{30}$th of its natural bulk, and consequently be liable to accident from explosion.

Before dismissing the subject of loco-motive engines, it ought to be remarked, that they must always be objectionable on a railroad for general use, where it is attempted to give them a considerable degree of speed; for many pass-places there cannot be; hence, the velocity of the greater part of the carriages on a line of road must be limited by a slow travelling one. This would not only be a source of inconvenience, but one of danger, from carriages striking against one another. A steam boat has sea-room; a mail has the width of the road, but a steam carriage cannot deviate from its track to avoid an

* Dr. Thomson's System of Chemistry, vol. i. p. 148.

accident. We therefore must now turn our attention to fixed engines; and examine if they afford any better reason to hope for the application of steam power with advantage and safety.

Fixed, or Station Engines.

Conceive, that the whole line of road is divided into short stages, and that an engine is placed at each of these to work an endless chain, extending the whole length of one or more stages, and running upon pulleys or rollers; also, that by simply moving the handle of a lever, having a friction apparatus, a carriage can be connected to the chain, and in a few seconds acquire and proceed at the same velocity, or be disconnected in an instant, if necessary. The consequences of such an arrangement would be, that the carriages would all move at the same velocity, that were attached to the same chain; and would not be liable to strike against one another. Any quantity of carriages, not exceeding the power of the engine, might be in progress at once; for any variation of the number would be regulated by the governor of the engine so as to keep the velocity the same, or nearly so. The engines could be of a better kind, kept in better condition, and under the care of better attendants, than any species of loco-motive engines.

We must next compute the extent to which motion could be conveyed by an endless chain, supported on rollers. The greatest stress a chain ought to be

exposed to is equal to the weight of half a mile of chain; consequently, the weight of chain to serve for one mile will be 2 times the moving power of the engine; * but if the rollers be properly formed, with a proper ratio between the diameter of the roller and its axle, the friction will be only about $\frac{1}{100}$ part of the weight of the chain, and consequently $\frac{2}{100}$ or $\frac{1}{50}$ part of the moving power will be lost in moving the chain, when the engines are one mile apart; and $\frac{1}{20}$ of the power will be lost in moving it, when the engines are $2\frac{1}{2}$ miles apart, and so on, till at 50 miles apart the whole power would be expended in moving the chain, for whatever greater power was applied, would strain the chain beyond that limit which, we have found, ought not to be exceeded.

From 8 to 10 miles may therefore be considered the greatest distance from station to station that ought to be adopted in practice; with the latter distance the loss of power will be one fifth.

It will be obvious, that a system which requires an engine at every 10th mile is only adapted for a rail-way of extensive traffic; but on a thoroughfare where the transit of goods and passengers would be sufficient to employ the necessary establishment, there can be no question of its answering the purpose. The same general principle of movement would act throughout, whether in ascents or descents or on the levels. One chain to move the

* The engine must draw in both directions at the chain, otherwise the stations must be at only half the distance apart, for it must be a double chain.

light carriages at their proper speed, and a separate double rail-way for heavy goods, with a chain moving at a slower rate.

The cost of the two systems would not be materially different to conduct an equal traffic, but the annual expenditure would be much less with station engines. The greatest difficulty would be the interruption of the line by other roads crossing it; which might be partly guarded against by choosing a proper line, and then to make one of the stations at each crossing.

Power of Low Pressure Engines.—We have shewn (p. 77), that the power of a steam engine is

$4873\,(459 + t) \times (\text{hy. log. } \frac{f}{f'})$ at the maximum, when worked expansively, and

$4873\,(459 + t) \times (1 - \frac{f'}{f})$ when worked at full pressure.

Now to find the value of f', we must allow for the force of the uncondensed vapour and the friction of the air pump. When the friction of the air pump is reduced to the effect at the steam piston, it will not exceed 1 inch of mercury; and let the force of uncondensed vapour be 3 inches, and the friction of the steam piston, as before determined,

$\frac{1}{4}f$ (see p. 79) then $f' = \frac{1}{4}f + 4$;* and

$$4873\,(459 + t) \times (\text{hy. log. } \frac{f}{\frac{1}{4}f + 4}) =$$

* The practical man will naturally inquire, how many pounds on the square inch does this give for the effective pressure on the piston? The inches of mercury are $f - (\frac{1}{4}f + 4) = 22\frac{1}{4}$ inches, or very nearly 11lbs. on the square inch for the full pressure.

the pounds raised one foot high, by the maximum power of a cubic foot of water converted into steam of the temperature t, and force f in inches of mercury.

Example.—Let the force of the steam be 35 inches of mercury, of $2\frac{1}{2}$lbs. above the pressure of the atmosphere in the boiler; the corresponding temperature is 220°; and

$$4873\ (459 + 220)\ \text{hy. log.}\left(\frac{35}{8\cdot 75+4}\right) = 3{,}350{,}000 \text{ lbs.}$$

raised 1 foot by one cubic foot of water converted into steam.

The table (Table II.) at the end of the work was calculated in this manner, and in the collection of tables we trust the reader will find a condensed, yet tolerably complete, view of the power, and expense of fuel for steam engines.

The maximum velocity for a low pressure engine bears the same relation to the length of the stroke as in a high pressure one (see page 84). We have not for either kind of engine attempted to determine the variation that ought to take place when the engine works expansively; but it cannot be very considerable.

CHAPTER V.

Of the Carriages for Rail-Roads—Weight of Carriages—Eight-Wheeled Carriages—Size of Axles and Wheels—Rules for Strength of Wheels—Resistance of Carriages compared with Experience—Height of Load and Distance of Wheels—Connexion of Horses to Carriages—Kinds of Axles and Guards against Accidents—Drags, Brake or Convoys for Carriages—Theory of the Brake—and its Application to Carriages.

CARRIAGES for common rail-roads are made strong, to resist the shocks they are exposed to at every change of velocity, and it is necessary to make the parts which come in contact, solid pieces, extending a little more than the length of the body of the carriage, and hooped at the extremities to prevent splitting; but carriages for passengers and for various kinds of goods must be provided with springs to reduce the force of these shocks.

The weight of carriages varies considerably in different rail-roads; in some cases the carriage is very little less than half the total weight, in others it is about $\frac{1}{3}$; but it is pretty evident, that when the wheels do not exceed about 4 feet diameter, the proportion may be reduced to $\frac{1}{4}$, and yet be sufficiently strong. In this case the load being 3 tons, the carriage will be 1 ton, making a total of 4 tons.

Small carriages must obviously be both heavier and more expensive, in proportion, than large ones. But as the stress on a wheel must be limited on a rail-road, we cannot much enlarge the carriages without adding to the number of wheels.

Eight-Wheeled Carriages.

When a carriage has more than four wheels, the body must be sustained so that its pressure may be divided equally among the wheels. In the case where 8 wheels are applied to support one body, if the body rests upon the wheel frame, of each set of four wheels, in the middle of its length (see fig. 26, Plate IV.); and is connected with those frames so as to allow the greatest possible change of level on the rails, it is obvious that each wheel must bear an equal pressure. If one frame with its four wheels be removed, and an axis with two wheels applied in its place, the carriage would have 6 wheels, and it would be easy to adjust the load so that the pressure on each pair of wheels would be equal.

By this mode of construction, carriages might be made capable of carrying 6 or 8 tons without requiring expensive rails. A less load than six tons for each carriage would render it extremely inconvenient, for a small carriage is often filled with one bulky package, though not loaded. The size of a rail-way carriage for the purposes of general traffic must not be less than that of a stage waggon (see p. 16).

The load on each wheel must be limited to suit

the strength of the rails; it will seldom exceed two tons on a wheel, nor be less than half a ton. The size of the axles may therefore vary from 2·2 inches to 3·5 inches, perhaps the most advantageous load will be about $1\frac{1}{4}$ tons on each wheel, which will require an axis of 3 inches diameter.

The size for the wheels is the next point to be considered; we have already shewn, Chap. III. p. 47, that in regard to power, there is much advantage in large wheels. But, practically, they must be limited to about 4 feet 6 inches, or, at the most, 5 feet, if made of cast iron; and even if made of wood with malleable iron rims, this size could not be much exceeded without rendering them very heavy; and the reduction of effect from the weight of a wheel becomes very considerable in ascents, though they add to it again in the descents. In level roads, the power required to move a heavy wheel is not great (see p. 42); and the size appears only to be limited by that which is best adapted for strength and durability. Now a cast iron wheel of 5 feet diameter is quite as large a one as we should consider it prudent to apply; and it certainly ought to be cast of the best tough iron, and carefully attended to, that unequal shrinkage in cooling may be prevented. For if a large wheel were to break from unequal tension in a carriage travelling at a quick rate, the consequences would be very serious. To diminish the risk from such an accident carriages ought to be provided with a species of feet, formed in such a manner, that in the event of a wheel breaking, the carriage would slide with that foot on the rails which corresponded

to the broken wheel; and the fall be not more than an inch or two.

We do not expect that wooden wheels can be made sufficiently sound to bear an occasional pressure of two tons on a wheel, without approaching so near to the weight of iron ones as to give no advantage, because their durability will be much less.

The parts of a wheel of cast iron to resist a given stress are easily proportioned; but in so doing we must always consider them liable to double the ordinary stress on the wheel. The easiest method is to consider the parts as solid rectangular prisms; and having found the bulk, let it be disposed in the form of greatest strength. The strength of the rim will be found by rule 2, art. 108, Tredgold on Iron; the distance from spoke to spoke being the length, and the strength of the spokes may be determined by rule art. 236 of the same work; and the distance of the direction of the force cannot exceed about the thickness of the spoke. The most advantageous form for section of the spokes is shewn by fig. 25, Plate III., as it must be one which will cast easily, and at the same time have as little material as possible collected in the neutral axis of the spoke. An example of the use of these rules will render the operation more familiar to those who are not frequently engaged in such calculations.

A wheel five feet diameter ought to have 12 spokes or arms, and supposing the load on such a wheel to be $1\frac{1}{4}$ tons, when the stress is equal upon each wheel of the carriage, then $2\frac{1}{2}$ tons, or 5600lbs, will be the greatest stress that can bear on the wheel. Each

spoke must be competent to resist this stress; and, considering it a square prism, and that the distance of the direction of the force is equal to the side of the prism, which will be about the extreme limit of its possible range, then the rule above quoted reduces itself to this simple form:—Divide the stress in pounds by 2200, and the product is the area of the spoke in inches, and this area may be disposed in the most advantageous form for strength as a set-off against the defects of casting, &c. Now the stress being 5600lbs. we have $\frac{5600}{2200} = 2{\cdot}55$ inches for the area, and its square root is 1·6 inches for the side.

The circumference of the wheel will be 15·5 feet at the mean diameter of the rim; hence the distance from centre to centre of the spokes will be nearly 1·4 feet, and, as this length multiplied by the stress in lbs. and divided by 850 times the breadth of the rim, is equal to the square of its thickness; making the breadth 4 inches, we have $\sqrt{\frac{1{\cdot}4 \times 5600}{4 \times 850}} = 1{\cdot}52$ inches, the thickness of metal to be disposed in the proper form for the rim.

Since the quantity of iron in the rim must be $4 \times 1{\cdot}52 = 608$ inches, and its circumference 15·5 feet, the weight of the rim will be 300lbs., and the weight of the spokes and centre 245lbs., making the whole weight of the wheel very nearly $4\frac{1}{2}$ cwt.

The weight of a wheel of 10 feet in circumference to bear the same stress will be nearly 2·6 cwt. when it has 10 spokes and the breadth at the rim is 4 inches as before.

Wheels for tram-roads may be calculated in the

same manner: the weight will be found less because there is not so much breadth wanted at the circumference as in edge rail wheels. In wheels for tram-roads 2 inches in breadth for each ton of stress on the wheel, will be about the proper breadth.

With 5-feet wheels for edge rails the weight of the waggon will a little exceed one-fourth of the total weight of the waggon and its load; with 4 feet 6 inch wheels it may be brought to one-fourth.

If the total load be 5 tons, or the waggon be loaded with 3¾ tons, and the axles be 3 inches diameter, the wheels being 54 in. or 4 feet 6 in.; and the ratio of the friction $\frac{1}{8}$th of the pressure, we have $\frac{3}{54 \times 8} = \frac{1}{144}$ part of the weight for the force that would draw the loaded carriage on level rails, or about 79lbs.

If the axles were very true and well made, and kept in good order, the ratio of the friction to the pressure might not exceed $\frac{1}{12}$, and then the same carriage would be drawn by $\frac{1}{216}$ part of its weight, or a force of 52lbs. But $\frac{1}{12}$ is the least friction we have observed, and under circumstances which we could not calculate upon in the construction of common carriages; hence we have not attempted to found our data upon such refined experiments.

As in several instances experiments have been made on the force required to move carriages on rail-roads, we may easily compare them with our own results.

Messrs. Stephenson and Wood are said to have ascertained, by experiment, that a loaded waggon of

8540 lbs. weight requires a force of only 49 lbs. to keep it in motion; which is $\frac{1}{174}$ part of the weight. Now the axles of these waggons being about 3 inches, and the diameter of the wheels 3 feet; hence the ratio of the friction to the pressure must have been $\frac{1}{14 \cdot 5}$.

In an experiment we have quoted in page 12, the ratio is given $\frac{1}{170}$; and most likely with similar waggons, though perhaps with smaller axles, as the waggon in the preceding experiment is stated to weigh $23\frac{1}{4}$ cwt.

We must therefore conclude that these are not results likely to exhibit the average resistance on a rail-road.

An experiment on the Penrhyn rail-way gives $\frac{1}{87}$ (see p. 25). The wheels are 14 inches diameter, and the axes probably $1\frac{1}{2}$ inches, and if this be the case the relation of the friction to the pressure is $\frac{1}{9 \cdot 3}$.

The part of the train drawn by one horse is, load 12 tons, carriages $2\frac{1}{2}$ tons, total, $14\frac{1}{2}$ tons, or 32,500 lbs.; the sine of inclination is $\frac{1}{96}$, hence by our rule (p. 51) for the descent of inclined rail-ways $32{,}500 \left(\frac{1}{87} - \frac{1}{96}\right) = 35$ lbs.

To draw the empty waggons up the inclination, the force will be $5600 \left(\frac{1}{87} + \frac{1}{96}\right) = 123$ lbs. nearly, shewing that the proper angle for a descending trade has not been attended to. The mean draught of a horse is $\frac{35+123}{2} = 79$ lbs., and the distance travelled per day is about 15 miles. But as this is much less

than the power of an average horse, we may infer that the resistance is somewhat greater than the experiment gives it.

On the Surrey rail-way the diameter of the wheels being 32 inches, and the axles $2\frac{1}{4}$ at the shoulders, we have $\frac{2\frac{1}{4}}{8 \times 32} = \frac{1}{108}$ for the friction at the axle; and if the resistance at the rails were only $\frac{1}{5}$th of this, the total resistance would be $\frac{1}{108} + \frac{\cdot 2}{108} = \frac{1}{90}$. Therefore the power necessary to draw 12 waggons down the inclination of 1 in 120 (see p. 16) would be $85568\left(\frac{1}{90} - \frac{1}{120}\right) = 241$ lbs. which is too much for a horse, though not beyond the power of a good one for so short a time, and we have most likely estimated the friction at the rails at more than its value in the new rail-way. But as one horse works one waggon loaded with 3 tons, making a total weight of about 4 tons, let us inquire what force he must exert to ascend the inclination, using the same data. Our rule (p. 51) gives $8960\left(\frac{1}{90} + \frac{1}{120}\right) = 176$ lbs. This must be near the actual resistance, and consequently we may assume as tolerably near the truth, that the resistance at the rails in a tram-road is about $\frac{1}{5}$th of the resistance at the axis. If we substitute the ratio $\frac{1}{60}$ instead of $\frac{1}{90}$ the resistance comes out more than the horses appear to work against.

Several other experiments have been made on the effect produced by horses on rail-ways,* but they

* Some experiments, on the quantity a horse can draw on a rail-road, were made by Mr. Wilkes, of Measham, in 1799. (Repertory

are defective in consequence of the ratio of the wheels to the axes not having been given; our comparisons however must have shewn, that the ratio of the friction to the pressure which we have assumed, is not far from that to which practice approaches.

In proportioning the body of a carriage, it should be kept in view that the load should be as low as possible, and particularly where the inclined planes are steep, for a high load in such cases produces a very unequal stress upon the wheels, and consequently upon the rails. If the height of the centre of gravity of the load be at the height, above the level of the axles, of half the distance between the axles, the whole stress will be upon the lower wheels on a plane of which the inclination is 45 degrees.

of Arts, vol. xiii. p. 167—171.) A horse drew 21 waggons, laden with coals, &c. and amounting in the whole to 37½ tons, up an inclination of $\frac{1}{115}$ with ease; and the same horse drew $\frac{1}{7}$ of the former load, or 5.36 tons, down the inclination with ease. Now if we suppose the force of traction to have been equal in both directions, we may find the friction by the rule for a descending trade (p. 59); we have $\frac{(n+1)}{115(n-1)} = \frac{7+1}{115(7-1)} = \frac{1}{86}$, or the resistance from friction was $\frac{1}{86}$ part of the load. Hence, we have $84000(\frac{1}{86} - \frac{1}{115}) = 243$lbs. the force of traction exerted by the horse. The same horse drew 3·2 tons up an acclivity of $\frac{2}{41}$; therefore he was capable of drawing $7168\,(\frac{1}{86} + \frac{2}{41}) = 430$lbs., and in this trial it was necessary to lock the wheels, the load was therefore about the extreme power of the horse.

In another experiment made at Brinsley colliery, by Mr. Wilkes, the friction is $\frac{1}{78}$ by the same mode of calculation. All these are extreme results as to the labour of a horse, and they are entitled to no further regard than to shew what effect can be produced for a short space of time, on occasions where it is required.

(See fig. 27, Plate IV.) Hence in cases where we wish to ease horses in ascending an inclined plane, it is an advantage to have larger hind wheels, for then the greatest stress is on the pair of wheels which have least friction; and, on the contrary, in descending, the small wheels which offer a greater resistance, have the chief part of the load. By this arrangement a horse could manage a carriage on inclinations, where without it he would be overrun by the carriage. On common roads the benefit of unequal sized wheels is greater; for on level roads the direction of the draught diminishes the pressure on the low wheels; and yet they have the full effect of their greater friction at every declivity; and the horses hold back in the most effectual direction to increase it.

When the inclination of the steepest plane is known, the proportion between the height of the centre of gravity and the distance between the axles, may be determined so that the pressure on the lower wheels may be only a given quantity. Thus, to limit it to two-thirds of the load, multiply the denominator of the fraction representing the inclination by the distance between the axles, and one-sixth of the product will be the height to which the centre of gravity of the load may be raised above the level of the axes, before the pressure on the lower wheels will be $\frac{2}{3}$ of the load.* For example, let the incli-

* The pressure on the lower axle will be $\frac{W \times AC}{AB}$; (fig. 27, Plate IV.); but $AC = \frac{1}{2} AB + h \tan. i$; hence $\frac{W \times AC}{AB} =$

nation be $\frac{1}{5}$; that is, one perpendicular to five horizontal; and the distance between the axles 48 inches; then, $\frac{5 \times 48}{6} = 40$ inches for the height of the centre of gravity of the load above the level of the axles, where the pressure of the lower wheels would be $\frac{2}{3}$ of the load.

When horses are employed to draw carriages on a rail-road, the traces should be attached so that the horse may draw in an ascending direction, and this direction gives a horse so much advantage in power to draw a load forward, that it should be obtained, by fixing the traces below the level of the axles when high wheels are employed. (See fig. 28.)

Where carriages are to be drawn by horses at a considerable speed, it will be necessary either to have the horses behind, or at the side of the carriage to prevent accidents. Perhaps the same security might be obtained by making the pole act on a brake at the circumferences of the wheels as soon as the horse held back.

The next point to be considered is the kind of axles. If the road be straight it is no matter whether the

$W\left(\frac{1}{2} + \frac{h \tan. i}{AB}\right)$ which is not to exceed n W; consequently we must have $\frac{1}{2} + \frac{h \tan. i}{AB} = n$; or $\frac{(n - \frac{1}{2})AB}{\tan. i} = h =$ the height of centre of gravity above the level of the axles; and the lower axle will always sustain the whole pressure of the load when $\frac{AB}{2 \tan i} = h$, as for instance, for 45° tan. = 1 and $\frac{AB}{2} = h$. When $n = \frac{2}{3}$, $\frac{AB}{\tan. i} = h$.

axles revolve or not; but, as Dr. Young has remarked,* whenever the motion deviates from a straight line, the wheels that are fixed on a single axis must one of them be dragged forwards, and the other pushed backwards; therefore we would prefer making the wheels revolve on fixed axles; because they must do less injury to the wheels and rails of the curved parts of the road, and require less power when, under any arrangement, there must be some lost by lateral rubbing against the guides.

As it is most desirable that wheels should be retained securely upon their axles, a variety of methods of rendering them secure have been proposed. One of the obvious properties of a good method is simplicity; it should be easily understood, and difficult to misapply or to mismanage; and, as the wheel is to be retained in its position by more or less friction against the parts which accomplish this object, it must be obvious that the rubbing parts ought to be as near as possible to the centre of motion. These conditions enable us at once to see the impropriety of using some of the methods that have been proposed; but these methods may be applied as a means of security.

It does not appear that any thing has been proposed that is more secure and simple than the common linch-pin; except those contrivances which act a greater distance from the centre of motion. Those which have the property of acting near to the centre, in common with the linch-pin, are too expensive for

* Nat. Phil. vol. i. p. 217.

ordinary carriages; and not necessary except where considerable speed is wanted.

Where wheels are secured by a linch-pin, they may be rendered more safe by adding the guard invented by Mr. Padbury.* The same principle has lately been applied to retain the wheel on the axis,† but though objectionable for that purpose, as it applies the guiding surface at too great a distance from the axis, yet it is very well adapted in the same form, for a safeguard to prevent the wheel coming off in case the linch-pin breaks, or is lost out. With some little variation we have shewn this guard as applied at the Ayr colliery (see fig. 29, Plate IV.); it differs from Mr. Padbury's, the latter consisting of a screw. This guard should be just clear of the collar or groove which is to receive it when the linch-pin is in, but when the linch-pin is out, either from neglect or accident, the wheel will be retained on by the guard.

Linch-pins ought to be made as strong as they can be made without weakening the axles, and they ought not to be too thin, for they are then very liable to be broken laterally; the principal strain on them being in that direction. They ought to be made of very tough iron, and indeed it would be well worth the additional expense to make them of tough steel.

For carriages designed for quick travelling with

* Transactions of the Society of Arts, vol. xxxi. p. 226. See also Phillips's application of the same principle, vol. xxxvii. p. 158.

† Dr. Brewster's Encyclop. art. RAIL-WAY, p. 309; or Glasgow Mechanics' Magazine, vol. iii. p. 2.

small loads, the axles invented by Mr. Collinge are best adapted.

There must be the means provided for regulating or stopping the carriages on a rail-way, where occasion requires; as for example, in the descent of an inclined plane a regulating power is necessary, and we have shewn in another place (p. 62) that even on a level part of the rails a carriage will run a considerable distance before its velocity be destroyed; hence, to be provided with a mode of increasing the friction, is of considerable importance.

On the Tyne and Wear rail-ways, the waggons are regulated by friction on the surfaces of the wheels, which is produced by the attendant pressing on the end of a bent wooden lever, called a *convoy*, which has its centre of motion fixed to the side of the waggon; the pressure on the lever causes it to rub against the opposite surfaces of the two wheels on that side of the waggon, and produces a friction proportional to the pressure on the handle.

Where the wheels turn on the axles, this plan is not adapted to the purpose; because its application on one side only, would give the waggon or carriage a tendency to run off the rails. There is a description of a method of applying a brake on both sides of a waggon, with a method of locking it at any pressure so as not to require the constant action of the attendant, in "Desagulier's Experimental Philosophy;" * which, though less simple than the

* Vol. i. p. 274; 1734. The rail-way of the stone quarries near Bath, with oak rails.

convoy used on the Tyne rail-ways, is a very good mode of regulating the descent, or of stopping a waggon where the wheels revolve on the axles; and it may be simplified, for it would be better not to make it act on each side separately.

An ingenious mode of retarding the motion of a carriage, is also described in the "Transactions of the Society of Arts,"* invented by Mr. Rapson; but it applies the friction at too small a distance from the centre of motion, for use on a rail-way. The action of the retarding force is similar to the friction of a brake-wheel; and, as a much greater degree of friction can be procured by a less pressure by applying this method, we will explain its theoretical principles, and shew our own mode of applying them to the subject under consideration.

Theory of the Brake-wheel.—As friction is proportional to the pressure, at least it may be considered so in practice, our first object must be to ascertain the pressure on the circumference on which the brake acts. Let W, (fig. 30, Plate IV.) be the weight or pressure which causes the friction, and let A be a short portion of the brake. Then, the block A is acted upon by the force W, and the stress on its connection to the next block B; these forces press the block A, on the circumference of the wheel; and if the direction and intensity of the force W be $a\,b$, it must be retained by an equal force $b\,d$, and the perpendicular pressure on the surface of the wheel will be measured by $b\,c$; the parallellogram $a\,b\,d\,c$

* Vol. xxxiii. p. 137; 1815.

being constructed on the directions of the forces. The force producing the pressure on the next block will be diminished by the amount of the friction on the first block; and so on in each succeeding one; but the ratio of the forces to the pressures will be constant; and, as the distance between the joints is to the radius of the circle passing through them, so is the pressure to the force which produces it. For $a\,b : b\,c :: a\,O : a\,d$. Hence, if s be the side of the polygon, whose angles correspond to the joints between the blocks, and n be its number of its sides occupied by them or the number of blocks, f the friction when the pressure is unity, and r the radius $O\,a$; then,

$$\frac{f\,s\,W}{r}\left(1 + (1 - f) + (1 - f)^2 + \ldots\ldots (1 - f)^n\right) =$$

the friction of the brake.

But the sum of the geometrical progression is, $\frac{1-(1-f)^n}{1-(1-f)} = \frac{1-(1-f)^n}{f}$; therefore,

$$\frac{s\,W}{r}\left(1 - (1 - f)^n\right) = \text{the friction.}$$

Now, the friction increases with the value of n, provided we do not reduce the length between the joints s in a greater degree, for the greater n is made, the less distance there will be between the joints. When the brake is to act on half the circumference, the friction will be the greatest when $n = 2$. Then, $s = 1{\cdot}4142$, and as the friction of fir on iron is about $\frac{1}{4}$ of the pressure, we ought to have 2 blocks, and $\cdot 62\ W$ = the friction. If the blocks are to occupy $\frac{2}{3}$ of the circumference, then 2 blocks will give the maximum, and the friction is $\cdot 75\ W$. If the friction

be extended to the whole circumference, then 3 blocks give the greatest effect, and the friction is = W; the weight which produces it.

It must be distinctly understood that these proportions are confined to the cases where the friction is $\frac{1}{4}$ of the pressure; and others must be computed from the formula $\frac{s\,W}{r}\left(1-(1-f)^n\right)$.

When the whole circumference is to be acted upon, it is evidently an advantage to take the halves separately; for then the friction is $2 \times \cdot 62\,W = 1\cdot 24\,W$, instead of being only equal to W; and this has been ascertained by experience, the best brakes being constructed in this manner.

To apply these deductions to the regulation of the motion of carriages, it must be remarked, that the power of the brake must be sufficient to stop the motion of the wheels, though this power should rarely be exerted; for the wheels would then slide on the rails, and both wheels and rails be injured.

We have found by experiment that a carriage would slide on the rails if the wheels were fixed when the moving force is $\frac{1}{6}$ of the weight; (p. 57.) consequently, the action of the brake on the wheels ought to be equal to this. Suppose the brake is to act on one wheel, and that the stress on the wheel is one ton, then, $\frac{2260}{6} = 373$ lbs., and $\frac{373}{\cdot 62} = 600$ lbs., the force that would be required at A, fig. 31, to stop the wheel so that it would slide on the rails, supposing the wheel to be moving in the direction indicated by the arrow. But a force of $(1-\cdot 62)$ $600 = 224$ lbs., will produce the same effect applied

at B. Let us suppose the opposite wheel to be acted upon at the same time by means of a horizontal axis C, which will render it necessary to apply a force of 448 lbs. by means of this axis. The force of a man to move a lever in such a case, may be put at 50 lbs., and $\frac{448}{50} = 9$ nearly, or the levers must be so proportioned that the man's hand will move over 9 inches, while the point B moves one inch. A spring to support the brake just clear of the wheel, and a ratchet to hold the lever at any degree of stress, should be added; and by means of a connecting-rod D, the lever may be at either end of the carriage.

CHAPTER VI.

On Selecting the Line for a Rail-Road—On Planning the Levels for a Rail-Road—Setting out the Inclination for a Descending Traffic—Ascents and Descents, Deep Cutting, Embankments—Bridges—Breadth of Rail-Roads—Width of Land required for Rail-Roads—Rail-Road for Messengers and Despatches—Passing Places and Turning Platforms.

THERE are very few subjects in the practice of civil engineering which demand so much particular information, profound skill, and such extensive views of the effects of trade and commerce, as the selection of a line for a rail-road or a canal. Nearly similar objects require the attention in both cases, but the peculiar properties of each must be considered. The man who has to rely for information on any material point, upon the knowledge of others, cannot grasp in his own mind the question in all its bearings. He must see in his own "mind's eye" the operation and effect of the work when complete; he must dispose of advantages to peculiar points, with due care not to affect the interests of the principal trade; and be prepared to embrace all the circumstances, which opening a new line of conveyance may be expected to call forth.

It is evident that, besides a complete knowledge

of the surface of a country, a knowledge of its internal structure and mineral contents, is necessary. Metallic ores, coals, lime, marl, building stone, &c. become valuable property in the vicinity of a rail-road; and at the same time a source of profit to its proprietors.

The interests of agriculture must also be understood, and such arrangements made as are likely to benefit the land-owners through whose property the line passes. For a road cannot be opened through an estate without inconvenience, to use the mildest expression, and that inconvenience ought, as far as possible, to be compensated by attention to every circumstance likely to enhance the value of the property. The conveyance of manure, marl, lime, &c. will naturally be encouraged, because it is the interest of both parties; while the tolls should be as low on these articles as will clear the expense of conveyance.

In consulting the interests of a manufacturing district, it must be recollected, that "*time* is an important element in all commercial transactions," and next in value is security; that economy should be attended to, we hardly need point out; but it should be real, and not apparent economy. This renders it evident that an engineer should be conversant with money affairs, and able to reduce to direct computation the advantage or disadvantage of cutting, embanking, &c. to obtain a direct communication, compared with that of a circuitous line. The mere interest and return of capital is not to be the sole object of consideration; the delay and of loss time

must also be considered; and such an excess of expense in cutting and embankment may be allowed as is considered equivalent to the importance of saving time.

In order to facilitate the choice of a line as it regards the surface of the country, the engineer may be reminded, that even in the disposal which nature has made of hills and valleys there is much system. Those things which to the first glance of the better informed, and at all times to the ignorant, appear to be without order or arrangement, are the result of the uniform action of natural causes, and are in reality capable of being traced and described with less difficulty than would be expected. Where a considerable tract of country is to be surveyed, the best index to its elevations and depressions is its streams and rivers; these indicate every change of inclination; and, to the experienced eye, with considerable precision. It will also be observed, that each river has its system of valleys; and except in a few instances, where the draining is effected by the outburst of an open stratum, a district, whose bounding ridge is easily traced, is drained by its river and system of valleys.*

* About five years ago, a model of England, in wood, was begun by a much-lamented brother, who died in 1822. It was to have been in separate squares, with the scale of elevations 5 times the scale of the plan; one of these squares is partly carved, and an immense quantity of information regarding sections, heights, levels, soundings, charts, &c. is collected. The principle to be acted upon was that of carving each river with its subordinate streams, as accurately as possible, and then proceeding to complete the valleys and ridges. It was an immense undertaking for

Having formed a tolerable idea of the best direction for the road, the next step must be to make a more particular survey, with a view to fix nearly the precise line. We would recommend the principal engineer to have this done by rectangular lines, as infinitely superior to surveying by triangles, in giving him an exact knowledge of the surface of the country. Perhaps, with the assistance of a diagram, we shall be able to render the advantage of this method obvious. Let A B (fig. 32, Plate IV.) be a portion of the intended line, and C D the breadth of country to be included in the survey. At any suitable distances choose stations *a a a*, their distance apart depending on the changes of level, and let the principal line A B, and also the cross lines *b b b b*, &c. be accurately levelled, and then drawn, as shewn in the figure, on the plan of the line of road. If the distance *b b* is required to be considerable, perhaps an additional line in the principal direction may be necessary. The etched lines shew the form of the surface at the line A B, *b b*, *b b*, &c. on the plan; and the latter being sections at right angles to A B, there is no difficulty in seeing the extent of cutting or of embankment that may be avoided by varying the position of the principal line. In fact, a plan of this kind, to a person familiar with sections, is better than a model of the country.

But, in proceeding to fix the exact line, it ought

one individual to conceive and set about; but ardent enthusiasm vanquishes difficulties; his knew no bounds; and perhaps it was his over-anxious pursuit of these inquiries which undermined his constitution.

to be ascertained, whether the trade will be an equal one in both directions or not. If an equal trade is likely to be established, then the line should be as level as possible. If a permanent unequal trade be the only one that can be conducted by the rail-way, and many rail-ways will be of this kind, then there is one inclination best adapted for the trade. We have shewn how to find this inclination in an algebraic formula (p. 59,) but here we shall give a rule in a more popular form.

Rule.—To the tonnage in each direction add the weight of the waggons required to carry the greater tonnage, divide the greater sum by the less, and make the quotient, diminished by 1, the numerator, and the same quotient, with 1 added, the denominator of a fraction. Multiply this fraction by the fraction representing the resistance on the level rails, and the result will be the fraction shewing the best inclination for the trade.

Let us suppose that it has been ascertained, that for every 1000 tons of goods or minerals that will go in one direction, there will be only 500 tons returned in the opposite one; and let the weight of the waggons to carry 1000 tons be 250 tons. Then, add to 1000 tons the weight of the waggons, which makes 1250 tons. Also, to 500 tons add the weight of the waggons, the sum being 750 tons. Divide 1250 by 750; that is, $\frac{1250}{750} = 1{\cdot}666$. Then, from 1·666 subtract 1 for a numerator, and add 1 for a denominator, and we have $\frac{\cdot666}{2{\cdot}666} = \frac{1}{4}$. Now, if 1lb. will draw 130lbs. on the rail-road, then $\frac{1}{4} \times \frac{1}{130} = \frac{1}{520}$,

or the descent, should be 1 part in 520, or very nearly 10 feet in a mile.

If the empty waggons only were to be returned, then $\frac{1250}{250} = 5$ and $\frac{5-1}{5+1} = \frac{1}{1 \cdot 5}$; hence,

$\frac{1}{1 \cdot 5} \times \frac{1}{130} = \frac{1}{195}$; or a descent of 1 part in 195, or nearly 27 feet in a mile. From these examples it will be evident, that this point requires to be attended to with some care, and particularly where horse power is employed; for much must be lost where the power required in the different directions is unequal.

The circumstances affecting the general inclinations or levels having been carefully considered, the next will be the ascents and descents.

Where either horse power or the steam carriage is to be employed, every ascent or descent which cannot be overcome without the aid of a stationary engine must be avoided, unless the expense of cutting or embanking will exceed the present money that would compensate for the delay and expense of the engine and its apparatus, attendance, &c. See Chap. VIII.

If stationary engines be employed throughout the line,* of the kind we have proposed (p. 89), then the height of the ascent or depth of descent will be immaterial, provided it be not too abrupt; and deep cutting may be in a great measure avoided. In form-

* We omitted to state, in its proper place, that these engines, at regular distances with endless chains, appear to have been first proposed by Mr. Edgeworth, (Nicholson's Journal, 8vo. series, vol. i. p. 223.) The velocity he thought obtainable, was 8 miles per hour.

ing embankments, the quantity of ground that will be injured by forming the necessary slopes to the embankment will depend on the nature of the materials of which the new ground will consist; for an embankment that would stand perfectly firm, and bear the action of the weather, when formed of sand, gravel, or the debris of rocks, and other materials that do not retain water in their fissures, would not last one winter if it chiefly consisted of clay. The same remark applies with equal force to cutting, where it is made through a stratum of clay, as we have an example in the Highgate archway.

A slope of 1 to 1, that is, a slope of 45°, is found sufficient for ordinary earth; for clay, 3 to 2, or a slope of 34° with the horizon, may often be required, unless it can be mixed with open materials, to prevent water collecting in the fissures produced by its shrinkage in dry weather. In other cases, so steep a face may be left as 2 to 3; or even 1 to 2; * and the slope that will be likely to stand may easily be judged of, by knowing the nature of the strata which will be cut through, and examining its state where exposed in the surrounding district.

In some cases, where good stone is at hand, a ravine or den may be crossed by arches, in a style similar to the ancient aqueducts; indeed, the structure of arches and bridges must frequently require the science and skill of the engineer of a rail-way. It is but recently that the scientific principles of bridges have been cor-

* A slope of 2 to 3 signifies the base is to the height as 2 is to 3, the first number always representing the base.

rectly treated, and it requires a separate treatise for such an important subject.*

The extent of land required for a rail-road must depend on the breadth and number of the tracks. The breadth of the track has rather been determined by opinion, than as a question arising out of the circumstances of the case. But it must be obvious, that the breadth of the track ought to have some relation to the height of the load, in order that the carriage may be always in stable equilibrium on the rails; and in rail-roads there is another circumstance to be considered, the pressure on the rails should not be materially altered by any slight depression of one side of the road. It may be taken as a general rule, for the width between the rails for carriages travelling at a greater speed than 5 miles per hour, that the centre of gravity should not be higher in proportion to the breadth between the rails than as 1 is to $1\frac{1}{2}$; but they are often so constructed that the height of the centre is equal, or nearly equal, to the breadth between the rails; and with this proportion, in slow motions, no ill consequence may probably occur; but in rapid motions, the centre of gravity must be kept at least within the limits we have mentioned, or there will be much risk of the carriage being overthrown by a very small obstruction. On a common road, the great resistance at the surface of the wheels, and the force of the moving power, tend

* On the subject of bridges, the reader may consult the article BRIDGE, in Napier's Supp. to the Encyclop. Brit.; and the article STONE-MASONRY, in the same work.

to keep the carriage from upsetting; but on a railway, the smallness of the moving force, and little increase of resistance to the wheel which takes the stress, render them insufficient to balance the momentum the carriage acquires by striking on an obstruction; besides, the connexion of the moving force is not so favourable for drawing the carriage back to its position. All these circumstances demand the serious attention of the engineer who has to conduct a rail-way where the carriages are to proceed at the rate of 10 miles an hour.*

The width between the rails being therefore dependent on the height of the centre of gravity of the loaded carriages, and this again varying with the nature of the load and the velocity, it will be obvious, we cannot do better than make the breadth between the rails such, that, by disposal of the load, the centre of gravity may be kept within the proper limit in either species of vehicle, whether swift or slow. And

* We speak of this as a rapid motion, and the more we consider the subject, the more reason we find to consider it so, and we see no material advantage in a greater speed, unless it were on a railway for messengers and letters only, where the small carriage to contain the messenger and letters may be impelled by a man, seated in it so that he could work in a manner similar to a man rowing. On a rail-way adapted for such a light carriage, with its load suspended below its axles, a great speed might be obtained, when habit had rendered it supportable; and perhaps it may in a few rare instances be worthy of trial, where the quick transmission of intelligence or despatches is of importance: and, being successful in these instances, it might be adopted for the conveyance of mails; but that any general system of conveying passengers would answer, to go at a velocity exceeding 10 miles an hour, or thereabouts, is extremely improbable.

it would be desirable that the same breadth and the same stress on a wheel should be adopted in all railways. We would propose 4 feet 6 inches between the rails for heavy goods, and 6 feet for light carriages, to go at greater speed. Hence, for a single road we may estimate 5 feet to the outside of rails, 3 feet on each side for path, and 4 feet on each side for hedge and ditch; or a total width of 19 feet. If the road be 6 feet between the rails, 21 feet will be required. For a double track we may allow 4 feet between the carriages, which will make the total width 28 feet for heavy carriages, and 32 feet for light ones. A double track for each species ought not to have less than a total width of 56 feet.

When a road-way of such considerable width is to be set out, some care will be required to adjust the cutting to the embanking, so that as little labour may be expended in moving earth as possible; and the sum of the masses transported, each multiplied by the space it is moved through, ought to be a minimum.* In side cutting, more skill is required in this respect than is apparent, till it be recollected, that a rail-road must deviate very little from a straight line, and the sides of hills are generally curved.

In all rail-roads it is necessary that there should be passing places at certain parts of the road, and in single tracks they should be very frequent. On the

* The reader who wishes to study this subject may consult Gauthey's Construction des Ponts, tome 11me, p. 195 et 391; or Belidor's Science des Ingénieurs, liv. iii., chap. viii., et note de l'editeur; ed. 1814.

side roads for passing, it would be desirable to place turning platforms for changing the direction of a carriage, either for returning or going off in a branch road; for it does appear to us a dangerous expedient to have either turning or sliding platforms on the principal lines.

CHAPTER VII.

Of the Construction of Rail-Roads—Rails for Rail-Roads — Advantages of Long Rails — Form, Breadth, and Strength of Cast Iron Rails—Effect of Percussion—Form, Breadth, Strength, and Durability of Malleable Iron Rails—Forming and Draining the Road, and Bedding the Blocks for supporting the Rails—Length of the Rails to render the Expense of the Road the least possible —Proper Materials to be in contact with the Rails — Construction of Embankments — Curved Roads—Strength and Form for Tram-Rails.

In treating of the construction of rail-roads, it will first be desirable to estimate the proper strength and form for the rails, and then proceed to the mode of fixing them. Edge-rails being first treated of in this manner, we shall then give the strength and form for tram-rails, chiefly with a view to their being applied for temporary purposes; for, as we have before stated, (p. 32,) they are not adapted for permanent roads. The strength we have assigned for the rails is the least that ought to be given, and for roads where there is considerable traffic, the strength ought to be increased according to the rate we give for that purpose, subject to the discretion of those who employ them.

Of the Rails for Rail-Roads.*

There are two kinds of rails which succeed in practice; these are wrought iron rails and cast iron ones. We can scarcely expect wrought iron to endure so long as cast, when exposed to the action of the weather, with the wet retained in contact, as it must be in a rail-way; but wrought iron has some other advantages of considerable importance, and which we will explain in this place, because it will render our investigation of their strength and proportions more direct.

A cast iron rail is more liable to fracture than a wrought iron one, even when made of the best and toughest cast iron; and the force that would break a cast bar would only give a wrought bar a small permanent depression, which would not interrupt the traffic on the road.

Again, a wrought iron bar is made of considerable length, while a cast iron one is seldom made more than 4 or 5 feet long; hence, the wrought iron bar is more effective in connecting the parts of the rail-way together, and the joints offer less obstruction to the carriage. But, whether long rails be of wrought or cast iron, it is extremely desirable that they should rest upon intermediate supports; and it is only the difficulty of adjusting these supports, so that the rails may bear equally upon them, which prevents cast iron rails being used in long lengths; for its flexure is so small before fracture, that a slight sinking of one of the supports would be the cause of the

rail breaking. Wrought iron, on the contrary, takes a set curvature to the depression of the support. In a very well-founded road it would be an advantage to use cast iron in longer lengths; but, for the reason above assigned, we could not trust to intermediate supports.

The reasons for preferring long lengths are the additional strength thereby obtained, and at no additional expense of material, and fewer joints. The short rail A B (fig. 15, Plate III.) is not so strong as the middle part C D (fig. 16) of a rail three times the length. If the ends E F of the long rail were firmly fixed, the middle part of it, C D, would bear nearly twice the load it would carry if cut to the length C D; it having the advantage of the strength of the bar at C and D. The parts E C and D F are also much stronger than when divided into short rails. In this arrangement, however, the strength is unequal; but it might be rendered nearly equal by dividing the whole length of the bar into 7 parts, and making the distance of the middle supports 3 of such parts, as in fig. 17. And if there be any other number of intermediate supports, it will be only necessary to make the end spaces to the middle spaces, as 2 is to 3. In long wrought iron rails this mode of supporting them will render them very nearly of uniform strength.

Cast Iron Edge Rails.

Respecting cast iron rails, we have to consider the form, the breadth of the upper side, and the strength.

The form should be that which gives the most strength with the least material; but, in our inquiry respecting this form, it must be remembered, that a form should be chosen which will suffer as little depression as possible when the load is upon the middle of the unsupported part of the rail; it being very obvious, that such depression must have the same effect as an undulating surface, in rendering the motion of the carriages irregular, and in increasing the draught. The breadth being uniform, the outline of the depth should be a semi-ellipse, so that the rail may be equally strong at every point to resist a load rolling over it; * but it is shewn in the "Essay on the Strength of Iron," that by adopting the form of equal strength, we shall have an increased depression in the ratio of 9 to 7; † and, as the saving of material is inconsiderable when the cross section of the rail is made of the best form, it would be better to use a rail of uniform depth.

In order to settle the form of the cross section of a rail, the breadth of the edge on which the wheels are to roll should be fixed upon, and this breadth should obviously be proportional to the load upon one wheel, when the diameters of the wheels are the same; but the larger the diameter of a wheel, the greater the surface of contact; and, consequently, for large wheels less breadth is necessary than for small ones. If we omit the influence of the wheel's diameter, and regulate the width by the stress upon the rail, it will be a sufficient guide for practice.

* Essay on the Strength of Iron, p. 49, second edition.

† Idem, articles 87 and 91.

We have observed, that in the neighbourhood of Newcastle the width of the upper edge of the cast iron rails is 2 inches, where the stress on each wheel is 1 ton. Therefore, as 1 ton : 2 in. : : W : 2 W, or the breadth in inches should be twice the weight upon one wheel in tons; which may be conveniently expressed by stating, that the breadth of the top rail should be an inch for each half ton of stress on one wheel.

The mean thickness ought not to be less than half the breadth of the upper side; and the least thickness of the section not less than half the mean thickness, or one-fourth of the breadth, and not less than $\frac{1}{2}$ an inch in any case. These proportions being settled, the quantity of matter may be disposed so as to give it the greatest degree of strength, by diminishing the thickness near the middle of the depth, and increasing it at the upper and lower surfaces, where it has most effect in resisting lateral stress; in the manner shewn in fig. 14, Plate II.

By adopting the above proportions, we render the calculation of the strength of rails very easy, and also that of their weight. The distance between the wheels of the carriages should be such that the unsupported part of a rail should have to carry only one wheel; and to allow for the increased stress on inclined rails, accidents, bad castings, or other defects, the rails should be calculated to bear double the greatest weight that is to be allowed on one wheel, besides the advantage gained by disposing the cross section in the most favourable manner for strength. The depth of the rail in

inches may be found by multiplying the distance between the supports in feet by 5·27, and the square root of the product will be the depth in inches.*

Example.—If the distance of the supports be 3 feet, then $5{\cdot}27 \times 3 = 15{\cdot}81$, of which the square root is very nearly 4 inches, the depth; and when the stress of one wheel is 1 ton, the breadth of the upper edge will be 2 inches; the mean breadth 1 inch, and the thickness at the middle of the depth half an inch.

The area of the section of the rail is equal to the depth multiplied by the mean breadth, and is, therefore, 4 inches; and the weight of a yard in length is $4 \times 3 \times 3{\cdot}2 = 38\frac{1}{2}$ lbs.†

For convenience of reference, a table is given at the end of the work, shewing the depth, breadth, and weight of rails for various lengths and degrees of stress, as calculated by the above rule; but in important works for considerable traffic, the breadths should be increased about one-third. The reason for this increase is, that, computing the fall which would

* If w be the weight on one wheel in tons, l the length between the supports in feet, and $b\,d$ the breadth and depth in inches, then (Tredgold on Iron, art. 106,) $\frac{2240\,w\,l}{850} = b\,d^2$, for cast iron, or $5{\cdot}27\,w\,l = bd^2$, when the stress is supposed to be double, to allow for accidents. But we have supposed the mean breadth to be half the breadth of the upper surface, consequently, when w is 1 ton, b will be 1 inch, and any other stress will require a breadth in proportion; therefore, $5{\cdot}27\,l = d^2$, or $\sqrt{5{\cdot}27\,l} = d$.

† The weight of a bar of cast iron 1 foot long and 1 inch square is 3·2lbs.

break such a rail as that in the above example, it appears that a wheel loaded with 1 ton falling from an obstacle somewhat less than $\frac{1}{4}$ of an inch high, would break the rail.* Long rails resist percussion better than short ones; a rail twice the length would resist a fall of $\frac{3}{8}$ of an inch.

Wrought or Malleable Iron Rails.

Malleable iron rails have been applied only as edge rails; and we have already noticed the advantage they possess in giving connexion to the parts and strength to the rails themselves. But it has been observed,† that the great weight on the wheels rolling on those rails extends the laminæ composing their upper surfaces, and at length causes these surfaces to break up in scales. This defect is a very serious one; it arises out of two circumstances, either of which would have little influence if taken alone. In the first place, all wrought iron rails are made too slight. It has been found, that an overstrain does not break them, but only gives them a set curvature, in proportion to the weakness, and hence the upper fibres become crippled and upset (to use a technical phrase very expressive of the fact).

This alone, perhaps, would not cause the surface to break up in scales, if it were not for the injury the rail receives by the mode of manufacture. The

* On this subject see the Practical Essay on the Strength of Iron, article 271.

† Mr. Chapman's Report on a Rail-way from Newcastle to Carlisle.

form of the rail is produced by passing it through rollers, and the cross section of the rails in use being irregular, the natural form of the rail, when rolled, would be a curve; and it is in giving straightness to it that its texture is destroyed. By making the cross section of a rail consist of equal and similarly disposed parts, (and such a rail is the strongest with the same quantity of matter,) we obtain a straight rail from the rollers, without injury to the external surfaces; and a bar of uniform depth being stiffer than one diminished towards the points of support, it becomes much easier to manufacture wrought iron rails than has been imagined.

The malleable iron rails being quite as soft, if not much softer than the cast iron ones, it is obvious that they should be at least of equal breadth on the upper surface; indeed, we think they should have a greater breadth, but, assuming that the same may answer in ordinary cases, the following will be about the proportions for these rails:—

An inch in breadth at the top for each half ton of stress on one wheel, and the average thickness $\frac{3}{8}$ths of the breadth at the top. If the rails be calculated to sustain the actual stress of one wheel without permanent depression, when of the average or mean thickness, the additional strength gained by the disposal of the parts of the cross section in the strongest form, will be a sufficient excess in this material, especially when we have the advantage of using it in long lengths, except for inclined planes, which should have stronger rails in proportion to the increased stress upon them.

To calculate the strength for a stress of 1 ton on a wheel, multiply the distance between the supports in feet, by 3·2, and the square root of the product is the depth required; and for any other stress make the breadth in proportion to the stress, and let the depth remain the same.*

If the distance of the supports be 3 feet, then $\sqrt{3 \cdot 2 \times 3} = \sqrt{9 \cdot 6} = 3\frac{1}{8}$ inches, nearly; the breadth of the top 2 inches, and the mean breadth $\frac{3}{4}$ of an inch; the parts disposed as fig. 14, which is drawn to a scale. The weight of a bar of iron 1 foot in length and 1 inch square, being 3·4 lbs., the area of the section in inches, multiplied by the length in feet and by 3·4, will give the weight in lbs. These calculations are made and inserted in a table at the end of this work, for all the probable cases.—See Table VIII.

Wrought iron rails have yet had but an imperfect trial; we expect they will be found of short duration; and in consequence of knowing that wrought iron, exposed in a similar manner to the action of moisture, does decay very rapidly. If a wrought iron rail-way has to be renewed entirely every 15 or 16 years, its expense must be more than commensurate to its advantages. We have inquired respecting the probable duration of wrought iron rails, and have had many opinions, but not a fact worth

* When w is the weight on one wheel in tons, l = the length from support to support, in feet, and b and d the breadth and depth in inches, we have $\frac{2240\, w\, l}{952} = b\, d^2$, (see Tredgold on Iron, art. 107, note), or $2 \cdot 36\, w\, l = b\, d^2$; and when $w = 1$ ton, by our proportion above settled, $b = \frac{3}{4}$, consequently $\sqrt{3 \cdot 2\, l} = d$.

transcribing. The process of decomposition is undoubtedly slow, but constant; and before putting down 40 or 50 miles of road with this material, there should be clear evidence of the time it is likely to last. There can be no question respecting the superiority of wrought iron for roads, where it is proposed that the carriages should go at a rate exceeding 3 miles an hour, if it be found that the duration is not so limited as to render them too expensive; for a broken rail would, most probably, cause a serious accident to a carriage in rapid motion. And in a road formed with cast iron rails, the rails must be exceedingly strong to guard against the risk of such accidents.

But, in order to prevent the displacement of a broken rail, in situations where this accident is likely to happen, there should be a continued paving below the rail, and it should be also retained in its place by a surface paving on each side of the rails. The crossings of roads, streets, &c. ought in all cases to be secured by these means.

The mode of forming the road for the reception of the rails must depend upon the nature of the ground. Where the ground is firm, it will be sufficient to remove the surface soil, and form the road to its proper inclination or level, as the case may be; and where the distances of the supports do not exceed about 3 or 4 feet, a continued trench, of about 2 feet wide and 10 inches deep, should be formed under each line of rail, with lateral or cross stone drains at a greater depth and suitable distance apart, for keeping the road dry: the cross drains having a descent in the most favour-

able direction for taking off the water, and land springs, if there be any.

The trenches under the lines of rails should be filled with small broken stone, or, in default of stone, with good gravel; giving the preference to hard stone broken as for roads, where it can be procured.

This being done in a proper manner, it would be an advantage to pass a heavy roller over the road before proceeding to set the blocks of stone, called sleepers, for supporting the rails. The blocks of stone should have a tolerably even base of about 16 inches square, and larger where a greater stress will be allowed than 1 ton on a wheel. The thickness about half the base. The place for each block should be rammed firm, and they should be bedded with fine gravel or coarse sand; using no more than is necessary to give each stone a firm and even bearing. As the goodness of the road depends much on the mode of bedding the stones, and on the accuracy of their adjustment, this part of the work must be carefully attended to. The chairs and rails being fixed to the stones, the horse-path and other paths may be formed of such materials as the district affords; but it would be desirable to make them firm and solid, because they contribute to the firmness of the blocks and rails.

In softer ground it will be necessary to form deeper and wider trenches, and to fill them by strata of broken stone, each stratum being about 7 or 8 inches in depth, and rammed to render it solid. And similar precautions will be necessary where the bottom is clay,

because clay is so much affected by dry and by wet weather.

If longer rails be employed, and in some instances the difficulty of obtaining a sound bottom will render this a good expedient, the best mode would be to build walls across the road at the proper distances for supporting the rails. Now, it is obvious, that if any support be incapable of sustaining half the weight of the waggon without injury, it is insufficient for the purpose; consequently, if the supports be ever so numerous, the same degree of firmness becomes necessary as if they were at a great distance apart. Hence, there is a length for the rails which is more economical than any other, for the rail becomes too expensive if it be longer than this length, and the supports become too expensive if it be shorter. The expense of one support being known, the proper length for the rails is easily calculated by an equation in the Practical Essay on the Strength of Iron; * we need not repeat the demonstration here, but will give the rule in words, and an example.

Rule for the most Economical Length for Rails of Rail-Roads.—The price of a ton of iron delivered on the rail-road must be known, and also the price of the chair, stones, and setting of one support. Then, divide the price of a ton of iron by the price of one support, being both in pounds; square the quotient and multiply it into the breadth of the rail in inches, and this product by one-twentieth part of the weight

* See Tredgold on Strength of Iron, p. 176, note, second edition.

of the loaded waggons in lbs. and extract the cube root of the last product.

Divide 700 by the cube root, and the result will be the distance between the supports in feet.

Example.—Suppose the price of a ton of iron, cast in rails and delivered, to be £14, and the expense of a support, for both materials and fixing, to be £0·2, the breadth of the upper edge of the rail 2 inches, and the weight of a loaded waggon 9000 lbs.

Then, $\frac{14}{0 \cdot 2} = 70$, and the square of 70 is 4,900.

Also, $4900 \times 2 \times \frac{9000}{20} = 4{,}410{,}000$.

The cube root of 4,410,000 is 164, and $\frac{700}{164} = 4\frac{1}{4}$ feet, very nearly.

Under these conditions, then, cast iron rails 4 feet 3 inches long would be most economical for the rail-road.

But if, from the nature of the ground or other causes, the supports cost 8 shillings each, or £0·4, then, by resuming the calculation, it will be found that the best length for the rails is $6\frac{3}{4}$ feet.

The price of iron, the weight of the loaded waggon, and the breadth of the rail, will also affect the distance of the supports, and, consequently, the expense of the rail-way.

We have not arranged the equation for wrought iron rails, but where it is required it may be easily done by reference to the work above quoted.

Every possible precaution should be adopted for keeping rail-roads dry, both by proper drainage, by being exposed freely to the sun and air, and by the

use of materials which do not absorb and retain water. In respect to the latter, the rail-roads to mines and collieries have advantages which will not be easily procured in other districts. Where wrought iron rails are tried, it will be found an advantage to bed round the rails with cinders, slag, or ashes, and to carefully avoid having clay, marl, porous lime-stone, or argillaceous sandstone, in contact with the rails.

In deep cutting the road will be almost constantly in shade; and, consequently, will require more attention to free it from water by drainage.

Embankments should be provided at proper distances, with a species of vertical drain, of broken stone or other open matter, partly to distribute the wet through its mass so as to accelerate its settlement, and partly to keep it from retaining more water than its due proportion; if the materials be of a retentive kind, proper drains at the base ought to be provided, to prevent any accumulation of water. And where embankment is necessary, the rails should be put down in a temporary manner, till the ground has settled and acquired its permanent degree of solidity.

When a considerable degree of curvature is given to a rail-road, the rails of the outer curve should have a slight rise to the middle of the curve, and the rails should be stronger in a lateral direction in both lines. The object of making a slight ascent to the middle of the curve of the outer rail, is, to counteract the tendency of the carriage to proceed in a straight direction, without its rubbing so forcibly against the

guides as we have observed in cases where roads have had a considerable curvature. Straight lines ought to be obtained if possible; but when it is determined to accomplish any object by means of a curved line, the rails should be cast or formed of the proper figure, as no combination of straight rails can be rendered free from angles, which both cause an irregular motion, and a great increase of lateral stress on the rails.

To calculate the strength for tram-rails, they may be considered as a rectangle, and the strength found by that means, the proper excess being gained by the disposal of the section in the best form for resistance. The rule for this case then, will be as follows:—

Rule.—Multiply 3 times the length of bearing in feet by the stress upon one wheel in tons, and divide this product by the breadth in inches. The square root of the quotient will be the depth of the rail in inches, supposing it to be a plate of uniform thickness. If this quantity of matter be put in the form shewn in fig. 19, Plate III., it will be sufficiently strong for the purpose.

Example.—If the tram-rail is to be 4 inches wide and 3 feet long, and the stress on each wheel is $\frac{3}{4}$ of a ton, then $\frac{3 \times 3 \times \frac{3}{4}}{4} = 1{\cdot}69$, and the square root of 1·69 is 1·3 inches. Therefore, a plate 4 inches wide, 3 feet long, and 1·3 inches thick, disposed in the form shewn in fig. 19, will be strong enough in this case, and its weight will be very nearly 50lbs.

Rails have been made much slighter than this,

and the consequence has been, that they have failed, and the roads been constantly out of order. If the rail were used in the state of a uniform plate, it would be just of that strength which renders the load incapable of producing permanent flexure, and by disposing the section in the form referred to, its strength will be about doubled.

CHAPTER VIII.

Of Estimating the Expense of Rail-Roads—Annual Expense of Rail-Roads—Rate of Tonnage for Rail-Roads, Canals, and Common Roads, to Repay the Expenditure—Expense of Horse Power, of Steam Carriages, of Stationary Engines, of Waggons and Attendants — Expense of Conveyance by Horse Power, by Rail-Roads, Canals, and Common Roads, and by Stationary Engines on Rail-Roads—Relative Advantages of Rail-Roads, Canals, and Common Roads—Expense of Deep Cutting and Embankment, compared with Inclined Planes—Rules for determining the most Economical Depth of Cutting—Direct Inclined and Circuitous Level Lines compared.

THE expense of a rail-road involves many particulars which are difficult to include in an estimate; hence, there must be some degree of uncertainty in such estimates; but, perhaps a little systematic arrangement of those items which usually occur, may assist in diminishing the quantity of the estimate which depends on probability. A still more important object directs our attention to this part of the subject, it is, the means of comparing the value of different modes of effecting the same end; or, whether a canal, a rail-road, or a turnpike, be best for a given

trade. And, as in a work on a great scale, where the capital is to be returned by small payments, more attention to method and real economy is necessary than in smaller concerns, the same mode of estimation applies to its parts. The success of such works depends entirely upon the facilities and the low rates of conveyance they offer to the public; consequently, every thing which tends to increase the one or to diminish the other, is worthy of attention.

The first cost of a rail-road must be considered, then the annual expense, and the rates of tonnage that will be equivalent to it, supposing the probable tonnage to be ascertained. To the rate of tonnage thus found, the rates that will repay the expense of the moving power, and wear and tear of carriages, must be added, which will give the real rate of tonnage.

If any given distance of rail-road has to be estimated, the expense of more or less of the following works will be required:—

1. Expense of examination, surveys, and leveling for the line of road; planning and setting out the line, &c.; and directing and superintending the work.

2. Value of the land occupied by the road, or its cuttings and embankments, passing places, fences and ditches, drains, &c.

3. Expense of cutting, embanking, and levelling the ground for the road.

4. Expense of ditches, drains, culverts, fences, and gates.

5. Expense of bridges, tunnels, and retaining walls.

6. Expense of blocks for supporting the rails, broken stone for bedding the blocks upon, and for horse path, gravel for foot paths, and ashes to bed round the rails; including labour in fixing and completing the same.

7. Expense of rails, chairs, pins, and fixing, including pointers and turn-out rails.

8. Expense of erecting toll-houses, weighing machines, turning wheels, transferring platforms, milestones, &c.

9. Expense of erecting engine houses and engines for inclined planes; of chains or ropes and rollers; regulating drums and brakes for ditto, including fixing, digging wells, and pumps.

10. Expense of paving crossings, streets, &c.

11. Amount of temporary damage to property in executing the work.

The annual expense will be the next object of inquiry; it is more uncertain than the first cost; but it will consist in the following particular expenses:—

1. Interest on the first cost, proportioned to the probable success of the undertaking.

2. Repairs to the rails, turning wheels, and platforms; including renewing, resetting, and keeping them in order.

3. Repairs, and remaking paths, fences, gates, and bridges; opening drains and ditches, &c.

4. Repairs to buildings, and machinery of inclined planes.

5. Expense of fuel for inclined plane engines, and attendance.

6. Principal engineer, assistants, toll collectors, clerks, &c.

These are expenses which are nearly independent of the tonnage; that is, the variation of tonnage must be very considerable to render them more or less; and before we proceed to examine the expense of different species of moving power, it will be perhaps an advantage to see what amount of carriage will be necessary to repay the capital expended on a rail-road, when its first cost is about the average to which rail-roads in different places may be expected to approximate.

The average cost of a proper rail-road, with a double set of tracks, will not be less than £5,000 per mile, when all the expenses in our list are included,* and the works are done in a good and substantial manner. Now, if the risk of expending capital on rail-ways, including the time before a dividend can be made, be equivalent to the risk of expending it in canals, (and we do not expect there will be a considerable difference,) the estimated return ought to be about £$8\frac{2}{3}$ per cent on the capital, the present rate of interest being assumed at $3\frac{1}{2}$ per cent. Hence, the annual rent per mile, to repay the first cost, ought to be $\frac{5000}{12}$ = £417 nearly.

* Mr. Chapman's estimate for the rail-road from Newcastle to Carlisle, is £3,915 per mile; and with the improvements suggested by Mr. Jessop, it will, no doubt, cost very nearly the amount of our average estimate. It is stated in the Quarterly Review, No. 62, p. 363, that the general average of a number of rail-roads, (some tram-rails, others edge-rails, some of cast iron, others of wrought iron,) containing upwards of 500 miles, is as nearly as possible £4,000 per mile, allowing them a double set of tracks; and the writer very justly remarks, that, from the imperfections of these old roads, we may extend the average to £5,000 per mile.

The repairs, renewals, and other annual expenses in 2d, 3d, 4th, and 5th articles of the preceding list, will not average less than 5 per cent on the cost of those articles, and that cost may be estimated, near enough for our present purpose, at £2,000 per mile. Hence the annual expense will be £100 per mile. The expenses for collectors, clerks, &c. may be put at £40 per mile, making a total annual expense of $417 + 100 + 40 =$ £557 per mile.

As the pence in a pound are 240, and the working days in a year 312, we have $\frac{557 \times 240}{312} = 428$; therefore, at 1 penny per ton per mile, the daily tonnage must be 428 tons, besides the expense of moving power; and if the tonnage be only half that quantity, or 214 tons, it must be 2 pence per ton per mile; and so of other proportions.

The preceding example will afford some idea of the quantity of tonnage necessary to render a railway a profitable speculation; and to make the extent of trade more easily understood, by using a measure as evident to the senses as possible, it will require 142 waggons, carrying 3 tons each, to pass the whole length of the line every day, to pay the tolls at 1 penny per ton per mile; but only 71 waggons will be required to pay the tolls at 2 pence per ton per mile.

Twopence per ton per mile ought to be the utmost that should be charged for tolls on the cost of a railway; and therefore, wherever a greater quantity of tonnage than 200 tons per day cannot be estimated upon with tolerable certainty, there will be very

little chance of a rail-way being a profitable speculation.

The average cost of a canal, under similar circumstances, may be estimated at double the cost of a rail-way, or £10,000 per mile;* and the repairs and expenses of attendance and management will be also greater than those of the rail-road; consequently, that the tolls may not exceed those of the rail-road, the tonnage per day must be nearly double, to produce the same return for the capital expended,—the advantage of canals being entirely dependent on the quantity that can be moved by a given power: but we shall defer our comparison of this part of the subject till we have estimated the expense of different kinds of moving powers.

The first cost of a turnpike road, with 16 feet of well-made road in the middle, will, at an average, amount to about £1,500 per mile, including the expense of land; and the annual repairs will amount to £100 per annum per mile, where the traffic is considerable. Now, allowing for no uncertainty of tolls, and supposing the money expended to be borrowed at 5 per cent, the loss of time in getting the road in a state fit to receive tolls being allowed for, the annual

* From a list of estimates for no fewer than 75 canals, including those of the greatest and least expense, a writer in the Quarterly Review, No. 62, p. 363, draws a general average of £7,946 per mile; but it is well known that these works have rarely, if ever, been executed for the estimated expense; in many instances the cost has been double the estimate, as, for example, in the Coventry canal, the Birmingham and Fazely, the Grand Trunk canal, and others. The Union canal cost £12,000 per mile, the Forth and Clyde, £12,400.

expense, including management, will not be less than £200 per annum per mile. Hence, the tonnage to defray this expense must be $\frac{200 \times 240}{312} = 154$ tons per day, in order that the tolls may not exceed 1 penny per ton per mile.

Therefore, it appears that a turnpike will answer when the tonnage is only $\frac{1}{3}$ of that required for a rail-road, when the tolls are the same per ton. The trade being 206 tons per day, the tolls would be 3 farthings per ton per mile.

These comparisons lead us to the next step in our inquiry, which is, the expense of different species of moving power.

The relative expense of different moving powers for rail-ways, is an interesting inquiry, and the same materials being necessary to estimate the absolute expense for any time or place, it is desirable to give some particulars to aid the researches of those who wish to make such comparative estimates.

The annual expense of a horse depends on—

1. The interest of purchase money.
2. Decrease of value.
3. Hazard of loss.
4. Value of food.
5. Harness, shoeing, and farriery.
6. Rent of stabling.
7. Expense of attendance.
8. Contractor's profit.

According to the average duration of a horse in a state fit for labour, of the description required on a rail-way, the first three items may be estimated at

one-fourth of the purchase money. The food, harness, shoeing, &c. included in 4th, 5th, and 6th, will most likely not exceed £40 per annum, nor yet be much short of that amount; and supposing one man to attend to two horses, this would add £15. 12*s.* if the man's wages were 2*s.* per day. And at this rate, the labour of a horse of the value of £20 would cost £60. 12*s.* per year; or, since there are 312 working days in the year, the daily expense would be 3*s.* 10½*d.* or 186 farthings; or, including the contractor's profit, 216 farthings per day.

But the power of a horse is 125lbs. when travelling at the rate of 3 miles per hour, and the day's work 18 miles (p. 68); therefore, $18 \times 125 = 2250$lbs. or near enough for our purpose, ¾ ton per mile when the carriages are deducted; and we have shewn that it is not probable that the moving power will draw more than 144 times its equivalent in weight, (p. 98,) or 108 tons one mile: hence the expense of conveyance by horse power on a level rail-road will exceed one farthing per ton per mile, in the ratio of 216 to 108, for power alone; or 2 farthings per ton per mile, may be calculated for horse power.

The annual expense of a high pressure locomotive engine or steam carriage, consists of—

1. The interest of the first cost.
2. Decrease of value.
3. Hazard of accidents.
4. Value of coals and water.
5. Renewals and repairs.
6. Expense of attendance.
7. Contractor's profit.

It is difficult to procure these particulars from the experience of those who employ engines: we will therefore annex, by way of example, such sums as we think likely to cover the expense. The first cost of the engine and its carriage may be stated at £50 per horse power; and its decrease of value and hazard, will render its annual expense about one-fifth of its first cost, or £10 per annum per horse power. The expense of fuel and water, per day, will be not less than $1\frac{1}{2}$ bushels of coals per horse power, and 14 cubic feet of water (see p. 82); and taking the coals at 6*d*. per bushel, and the water and loading with fuel at 3*d*. the annual expense will be £15. 12*s*. The renewals and repairs, at 20 per cent on the first cost, will be £10, which is as little as can be expected to cover them. Attendance, suppose one man and one boy for each 6 horse engine, at 6*s*. per day, or 1*s*. per day for each horse power, or £15. 12*s*. per annum. Therefore, the total annual expense of one horse power, would be £51. 4*s*. or 158 farthings per day. This power is equal to 3,000lbs. or $1\frac{1}{3}$ tons per mile, for the force of traction, or deducting the weight of the carriages 1 ton per mile in one day, and $144 \times 1 = 144$ tons one mile on carriages; which makes the expense of conveyance 1·1 farthings per ton per mile, or $1\frac{1}{3}$ farthings per mile, including the contractor's profit, with an addition for the extra expense of the rail-road for the steam carriages.

From these calculations it appears, that wherever the line of a rail-road does not extend to such a distance from collieries as to increase the price of

coals, equal in quality to Newcastle coals, to more than an average price of 6*d*. per bushel, or 13*s*. 5*d*. per ton, the locomotive steam carriage is $\frac{3}{8}$ less expensive than horse power. But it is assumed in these calculations that 1½ bushels of coal is to produce the same effect per day, as the elementary horse power; and consequently, that the engines are superior to those now in use; also, that the waste steam is applied to warm the water for the boiler, so as to render the road-side boilers unnecessary.* See p. 81.

When the steam is made to act expansively, a greater effect will be obtained by the same quantity

* The coal required to produce a useful effect of 144 tons one mile, according to our estimate, is 1½ bushels, or 126lbs.; that is, 0·875lbs. per ton per mile; and as some experiments have been made on this subject, we ought to compare them. In an experiment made at Killingworth colliery, on the 17th of January, 1825, 12 waggons, carrying 54 cwt. each, were drawn 2½ miles in 40 minutes, by a locomotive engine which consumed 4½ pecks of coals to produce this effect. The Newcastle peck of coals is 34½lbs. but we will suppose this to have been the common peck of 21lbs.; then the quantity of coals will be 94½lbs. and the effect 32·4 tons, moved 2½ miles, is equivalent to 81 tons moved one mile, or 1·17lbs. of coal were required to move one ton one mile; in addition to this, the boiler was supplied with hot water.

In a second trial, 8 waggons, containing 21·6 tons of coal, were conveyed 2½ miles by 4 pecks of coal, in 36 minutes, which is equivalent to one ton conveyed one mile by 1·55lbs. of coal.

In the third trial, 6 waggons, containing 16·2 tons of coal, were conveyed 2½ miles in 32 minutes, by 5 pecks of coal, which is equivalent to one ton conveyed one mile by 2·6lbs. of coal.

The mean of the three trials is 1·74lbs. The irregularity has obviously been occasioned by the state of the steam, it being strong at the commencement of the experiments, and exhausted in the following ones. The waggons ascended 1¾ miles up a rise of 1 in

of coal; but in that case larger cylinders will be required.

The annual expense of impelling carriages by low pressure steam engines moving endless chains, will consist of—

1. The interest on the first cost of the engine, engine buildings, wells, reservoirs, pumps, and land for erecting them upon, chains, rollers, standards, drums, and other machinery.

2. The decrease of value by wear and tear, and insurance.

3. The expense of renewals and repairs.

4. Fuel and water.

792, and descended again down the same plane; and, therefore, the mean effect would be nearly the same as for a level plane.

The result of these trials led us to state, (in p. 82,) that on the Newcastle rail-roads, about 3 bushels of coals would be consumed to produce the effect called a horse power in engine calculations. A more recent trial shews that they can do with less; for in an experiment tried on the 22d of January, 1825, at Killingworth, it appears that 12 waggons, containing $33\frac{3}{4}$ tons of coals, were drawn $9\frac{1}{2}$ miles by a steam carriage which consumed 360lbs. of coal to produce this effect. Now, $33\frac{3}{4} \times 9\frac{1}{2} = 320\frac{5}{8}$ tons drawn one mile; and $\frac{260}{320\frac{5}{8}} = 1\frac{1}{8}$lbs. per ton per mile, very nearly; which exceeds the proportion in our calculation nearly $\frac{1}{4}$ of a lb. per ton per mile. The engines and roads had been in use several years, excepting a small part where the road was formed with malleable iron rails, in passing over which, the carriage acquired more speed: but as a rail-road must last several years to be of any use to the public, its state may be taken as a fair enough average; for in other respects it was undoubtedly an experiment to shew the subject in its most favourable light. It would have been more to our purpose to have seen a statement of the actual quantity of coals consumed in a month, and the quantity of coals carried in the same time to a specified distance from the pit.

5. Expense of attendance.
6. Contractor's profit.

This mode of applying power is evidently limited to the case where the traffic is considerable; and it ought to be estimated by the expense of the whole line in the same manner as the expense of the rail-way itself; but without estimating to a design for a rail-way, with this kind of moving power, we could not arrive at an accurate result; it will, however, approach very nearly to $\frac{1}{5}$ of the annual expense of the rail-way itself. Therefore, whatever rate of toll is found necessary to cover the expense of the rail-way, it will require an addition of $\frac{1}{5}$ to pay the expense of the moving power, when the tonnage is 428 tons per day, or $1\frac{1}{4}$ farthings per ton per mile.

There yet remains another expense to be considered before we have all which must be paid by the transit of goods, and this is, the expense of carriages and of attendants, where either locomotive or stationary engines are employed.

The first cost of carriages will be, at an average, about £10 per ton, and stating the repairs and renewals at one pound per ton per annum, the annual cost will be about £2 per ton, or 7 farthings per day for each ton, including profit.

If one attendant be allowed to each carriage, or set of carriages, which conveys 6 tons, the expense per day at 2*s*. 4*d*. is—

	112 farthings.
Expense of carriages $6 \times 7 =$	42
Total expense per day . . .	154, or 26 farthings per ton, nearly.

We are now in a state to compare the different kinds of power and expence of conveyance on the average estimates, in order to shew the mode of managing more accurate ones, when made for particular lines of road.

Expense of Conveyance by Horse Power.—We have found the expense of a horse and attendance to be 216 farthings per day, and the expense of a waggon, to convey 6 tons, will be 42 farthings per day, making a total of 258 farthings; and the day's work being 18 miles, when the rate is 3 miles per hour, and the stress on the traces 125lbs. it will be equivalent to $6 \times 18 = 108$ tons, drawn one mile, and $\frac{258}{108} = 2{\cdot}4$ farthings per ton per mile.

And where the estimated traffic is 428 tons per day, we have found that the toll, to pay the expense of the rail-road, must be 4 farthings per ton per mile; hence, the total expense of conveyance in such a case will be 6·4 farthings per ton per mile.

If the estimated trade be 200 tons per day, it will be 10·4 farthings per ton per mile; but if the traffic be 856 tons per day, the toll to pay the expense of the rail-road would be only 2 farthings, or the total expense of conveyance only 4·4 farthings per ton per mile, or perhaps we may say 5 farthings, to cover the increased wear and tear.

The cost of a canal for a trade of 856 tons per day, would render the expense of conveyance 1 penny per ton per mile, for tolls (p. 143.) And the day's work of a horse being about 22 tons, drawn 23 miles,* or 506

* Smeaton states that 22 tons burden, at from 2 to $2\frac{1}{2}$ miles per hour, is the work of a horse on a canal (see Reports, vol. i. pp. 145

tons drawn one mile; we have $\frac{216}{506} = 0{\cdot}427$, making the rate 4·427 farthings per ton per mile, without including additional attendance, or wear, tear, and expense of boats. And we may from these calculations infer, that where the trade is less than 1,000 tons per day, canal conveyance is more expensive than that by rail-roads, even when horse power is employed, with the disadvantage of a slower rate of travelling.

On a turnpike road the greatest useful effect will not average more than $\frac{3}{4}$ of a ton, drawn 18 miles by one horse in a day; or 13·5 tons drawn one mile; and tåking the expense of a horse and attendance at 216 farthings, and 7 farthings for a cart, we have $\frac{223}{13{\cdot}5} = 16\frac{1}{2}$ farthings per ton per mile, for expense of power and attendance.

Where the amount of the trade is 206 tons per day, there will be 3 farthings to add for tolls, (p. 143,) making $19\frac{1}{2}$ farthings, or very nearly *5d.* per ton per mile, or nearly double the expense of conveyance on a rail-road for the same trade.

When the trade is not more than 100 tons per day, the expense of carriage on a rail-road is nearly the same as on a turnpike, while on the latter there is a

and 168.) And Mr. Bevan has informed us, that the horses on the Grand Junction Canal usually travel 26 miles per day, and draw a boat containing about 24 tons, at the rate of about 2·45 miles per hour; the empty boat being nearly nine tons, the total mass moved is about 33 tons; and the average force of traction he found to be only 80lbs.

convenience of delivering goods to any situation, which cannot be obtained by a rail-road.

Expense of Conveyance by Steam Carriages.—We are of opinion that the rate for these carriages ought not to exceed 6 miles per hour, or 60 miles per day; at which rate the expense of attendance and carriages will be 26 farthings per ton for 60 miles, or $\frac{26}{60} = \cdot433$ farthings per ton per mile. This, added to 1·333 farthings for the steam carriage, its attendants, and fuel, makes the total expense 1·766 farthings per ton per mile, or nearly $\frac{3}{4}$ of the expense of horse power; but if the horses were to travel at the same velocity, the expense would be only $\frac{3}{7}$ of the expense of horse power. To these the tolls of the rail-road are to be added, which are nearly the same whatever species of power be employed.

Expense of Conveyance by Stationary Engines.—The expense of this species of power will be very nearly the same as for steam carriages at the same velocities; by following the same steps, we find it 1·683 farthings per ton per mile.

In either case, when the tonnage is above 800 tons per day, the total expense of tolls, carriages, and moving power, is less than 1 penny per ton per mile, which is less than the tolls alone of a canal for the same trade, when the profits to the adventurers are the same in both cases. And unless it be in districts extremely favourable for the construction of a canal at a small expense, the rail-road will be the cheaper mode of conveyance whenever the daily tonnage is less than about 15 or 1600 tons.

But, when it is recollected that on a rail-road goods may be propelled with more than twice the velocity that can be obtained on a canal, and without increasing the expense of conveyance, we think it must rarely be considered advisable to cut a canal, in preference to making a rail-road. And if similar modes of computation had been applied to canals, the instances of unprofitable and losing speculations would have been less frequent.

Having shewn the relative expense of different modes of conveyance for goods, and the extent of trade to which each method is applicable, our next inquiry may be directed, with some prospect of use, to ascertain what length of rail-road is likely to be productive. When a load is to be transferred from one carriage to another, we cannot allow less than about 3*d.* per ton for each change; and in the case of coals or other like articles, we would recommend that they should be loaded in boxes similar to those now used for containing the loading of the coal keels in the Wear; one of the boxes to contain the load of a single-horse cart, and of a size suited for being taken to its destination by one. The transfer would be then very expeditiously effected by a proper crane, and without injury to the coals or other goods.

The expense of conveyance by a common road being 5*d.* per ton per mile, and by a rail-road suppose 2*d.* hence, it is obvious that no advantage whatever can be gained by a rail-road only 2 miles in length, when the goods have to be transferred to send them to their respective destinations; and the expenses and incon-

venience of such a mode of conveyance will probably render a length of 5 or 6 miles of very little value for general trade.

As inclined planes are not only an inconvenient, but an expensive mode of passing over a ridge or a valley, it is an important part of the theory of rail-roads to shew what degree of cutting or embankment will be compensated by lowering the ridge.

The loss from ascending and descending by inclined planes, arises from two circumstances: the one is an actual increase of length of line; the other is the loss of power by friction, preponderance, and expense of attendance.

Let the loss for preponderance be f', and the angle of inclination to which the plane may be reduced, be denoted by i: the angle in the natural state being h. Also, let F be the resistance of the carriages when the total load is $1\frac{1}{3}$ tons on the level rails, or an effective load of one ton.

Then, the power on the level rails will be to the loss of power in tons per mile, by the ascent, when the length of the base of the ascent is l yards, as

$$1760 : \frac{l}{\cos. h} :: f' \text{ F} \sin. h : \frac{l f' \text{ F} \sin. h}{1760 \cos. h} = \frac{l f' \text{ F} \tan. h}{1760}.$$

And when the descent is the same, the power lost on the descent will be o. By the same means, the loss of power on the inclination i, is found to be $\frac{l f' \text{ F} \tan i}{1760}$. Consequently, the reduction of loss by reducing the inclination to any angle i, is $\frac{l f' \text{ F}}{1760}(\tan. h. - \tan. i.)$

If a represent the annual produce of the carriage of one ton one mile, then the annual loss by the ascent and descent is $\frac{l f' F a}{1760}$ (tan. h — tan. i.)

To find the annual expense of the additional length of rail-road, put E = the expense per mile; and $\frac{E}{p}$ the annual rent that will repay that expenditure of capital; then, $\frac{l E}{880 p}$ (sec. h — sec. i) = the annual value of the increased length of road; which is equal $\frac{l E}{880 p}\left(\frac{\cos. i - \cos. h}{\cos. h \times \cos. i}\right)$.

Hence, the total annual loss is

$$\frac{l}{880}\left\{\tfrac{1}{2} f' F a (\tan. h - \tan. i) + \frac{E}{p}\left(\frac{\cos. i - \cos. h}{\cos. h \times \cos. i}\right)\right\}.$$

Now, in order that no excess of expense should be incurred by cutting or embanking, the interest of the capital expended in such works ought not to exceed the above sum.

The expense of moving ground is measured by the cubic yard, and l in the preceding equation is the length of half the base line in yards. Put b = the breadth in yards, c the cost of moving one yard in fractions of a pound, and n = the base of the slope, on each side of the road, when its height is unity.

The cutting or embanking on each inclination will be composed of a wedge-formed solid, and two triangular pyramids, and the content of the two wedge-formed solids will be $b\, l^2$ (tan. h — tan. i) cubic yards.

And the content of the four pyramids

$$\frac{4 n l}{3}\left(l (\tan. h - \tan. i)\right)^2 \text{ cubic yards.}$$

The sum of the quantities by the interest is

$$\frac{l^2 c}{3p}\left\{3\,b\,(\tan. h - \tan. i) + 4\,n\,l\,(\tan. h - \tan. i)^2.\right\}$$

Hence, that there may be no loss by cutting or embanking, we must have

$$\frac{l^2 c}{3p}\left\{3\,b\,(\tan. h - \tan. i) + 4\,n\,l\,(\tan. h - \tan. i)^2\right\} =$$

$$\frac{l}{880}\left\{\tfrac{1}{2} f'\,\mathrm{F}\,a\,(\tan. h - \tan. i) + \frac{\mathrm{E}}{p}\left(\frac{\cos. i - \cos. h}{\cos. h \times \cos. i}\right)\right\}.$$

If we substitute d, the depth of cutting at the summit, for its equal, $l\,(\tan. h - \tan. i)$; we have

$$\frac{l\,c}{3p}\left\{3\,b\,d + 4\,n\,d^2\right\} = \frac{\tfrac{1}{2} f'\,\mathrm{F}\,a\,d + \frac{l\,\mathrm{E}}{p}\left(\frac{\cos. i - \cos. h}{\cos. h \times \cos. i}\right).}{880}$$

When the rails are level at the reduced inclination, then $\cos. i = 1$; and we shall not commit a material error by making it 1 for all cases; and by that means we free the unknown element of the equation from its involved state, and have

$$d = \sqrt{\frac{\mathrm{E}\,(1 - \cos. h)}{1173\,c\,n\,\cos. h} + \left(\frac{3\,b}{8n} - \frac{p\,f'\,\mathrm{F}\,a}{4963\,l\,c\,n}\right)^2} - \frac{3\,b}{8} + \frac{p\,f'\,\mathrm{F}\,a}{4963\,l\,c\,n}.$$

When $\mathrm{F} = \frac{1}{144}$ of $1\frac{1}{2} = \frac{1}{108}$; $f' = \frac{1}{2}$; $p = 25$, $n = 1$; $b = 8$ yards, E = £2,500; a = £700; and c = £$\frac{1}{160}$; we have $\sqrt{\frac{340\,(1 - \cos. h)}{\cos. h} + \frac{(3\,l - 1{\cdot}3)^2}{l^2}} - \frac{3\,l - 1{\cdot}3}{l} = d$, the depth of cutting; or near enough for use, where the length of inclination is considerable.*

* The general equation may also be reduced to

$$d = \sqrt{\frac{\mathrm{E}\,(1 - \cos. h)}{1173\,c\,n\,\cos. h} + \left(\frac{3\,b}{8\,n}\right)^2} - \frac{3\,b}{8\,n}.$$

$$\sqrt{\frac{340\,(1 - \cos.\,h)}{\cos.\,h}} + 9 - 3 = d.$$

In this equation, cos. *h*, is the cosine of the angle of the natural slope of the ground, and *d* the depth of cutting at the summit in yards.

It will readily appear from these equations that it is much less expensive to nearly follow the undulations of the surface, than to make either deep cutting or embankment beyond those limits, which are easily determined by half an hour's labour, in applying the equations to the case under consideration. We have inserted numbers and shewn how to reduce it to the case of a road of average expense; and if a few examples be added, it will assist in removing those extravagant notions respecting cutting and embanking, which sink the capital of the country in unprofitable speculation. Excessive first cost renders a project ruinous to the proprietors; it creates a temporary demand for labour which is injurious to the country, while it diminishes the quantity of permanent employment.

Example I.—In a case where the line of a rail-road crosses a ridge of which the natural ascent is at an angle of 5 degrees, required the depth of cutting at the summit, and of embankment in the valley, which will not increase the rate of tonnage on the rail-road.

By a table of natural sines, the cosine of 5 degrees will be found to be 0·99619; therefore,

$\sqrt{\frac{340\,(1 - 0{\cdot}99619)}{0{\cdot}99619}} + 9 - 3 = 0{\cdot}2$ yards. This shews that it is more economical to employ a greater power,

than to alter the ascent more than 0·2 yards, or about $7\frac{1}{4}$ inches.

Example II.—If the natural rise of the ground be at angle of 12 degrees, then, cos. $12^{\circ} = 0{\cdot}97815$

and $\sqrt{\frac{340\,(1 - 0{\cdot}97815)}{0{\cdot}97815}} + 9 - 3 = 1{\cdot}06$ yards.

Example III.—If the natural inclination of a ridge be 45 degrees, then, cos. $45^{\circ} = 0{\cdot}7071$, and

$\sqrt{\frac{340\,(1 - 0{\cdot}7071)}{0{\cdot}7071}} + 9 - 3 = 9{\cdot}2$ yards, or nearly

$9\frac{1}{4}$ yards for the quantity the ridge may be lowered at the summit; and of course the valley would be equally raised by moving the materials. Deep cutting must therefore be attended with very considerable additional expense, where it exceeds these proportions; they are independent of the length of cutting, because the extra expense in either mode is proportional to the length. In these calculations we have omitted to calculate for the extra quantity of ground required for deep cutting and embanking, and we have allowed $1\frac{1}{2}d.$ per cubic yard for cutting, and the same price for embanking; making the total expense of moving the ground $3d.$ per cubic yard. This mode of dividing the price is adopted for the application to the equation. Where the expense of moving the ground is different, a greater or less depth of cutting may be necessary, according as the price is less or more than the one we have calculated upon.

In some cases it will be possible to avoid inclinations by a circuitous level road. To ascertain the increase of distance which will be equivalent to

passing the inclinations, we may resume the equation in p. 155, making l the total length of inclination in miles; $f' =$ the loss of power on the inclined planes; $F =$ moving force per ton added to the weight of the carriage; $a =$ the annual produce of a mile of road ($\frac{E}{p}$ must be equal a in this case;) $h =$ the angle of inclination of the road on the inclination; and $L =$ the additional distance in miles by the circuitous line. Then,

$$La \doteq l\left\{\tfrac{1}{2}f'\,F\,a\tan.h + a\left(\frac{1-\cos.h}{\cos.h}\right)\right\}$$

$$\text{or, } l\left\{\tfrac{1}{2}f'\,F\tan.h + \left(\frac{1-\cos.h}{\cos.h}\right)\right\} = L.$$

If we have a case where $F = \frac{1}{108}$, $f' = \frac{1}{2}$, $p = 25$, and $a =$ £700, the equation becomes

$$l\left(\frac{\tan.h}{432} + \frac{1-\cos.h}{\cos.h}\right) = L.$$

Example.—In a line of road where the length of the base of the inclined rails is 6 miles, and the angle of inclination 12 degrees, to find the increased distance by a circuitous level road that would render the expense of the two lines equal.

In this example $l = 6$, and $h = 12^{\circ}$; hence,

$6\left(\frac{\cdot212}{432} + \frac{1-0\cdot97815}{0\cdot97815}\right) = 0\cdot137$ miles, nearly $\frac{1}{7}$ part of a mile, or about $\frac{1}{44}$ part of the distance. If a level road, not exceeding this increase of distance, could be obtained under the circumstances described in the example, it ought to be preferred, provided it does not deviate much from a straight line. Other cases may be calculated in a similar manner.

We have now, we trust, considered some of the

most important points in the theory and construction of rail-roads; and if we have not found reason to agree with others who have treated the subject, either in estimating the expense of conveyance or its rapidity, still we agree with them in considering the rail-road an important link in the system of land conveyance, and one which the increased trade of this country must, sooner or later, bring into extensive use.

It is too true, that the introduction of a new and useful improvement always is attended with loss and inconvenience to those who have an interest in the methods before in use; but, though we may lament that such a concomitant evil should attend the progress of discovery, it would be absurd to allow it to operate in retarding the adoption of any improvement from which there will result a national benefit. That spirit which rejects improvement from interested motives, ought not to exist in a civilised nation; and certainly it should have neither protection nor encouragement. The encouragement ought rather to be given to those whose private interest is to promote the public good.

CHAPTER IX.

Table of the Power of Steam in High Pressure Engines—Table of the Power of Steam in Condensing Engines—Table of the quantity of Coal equivalent to a Horse Power in High Pressure and in Condensing Steam Engines—Table of the effect of a given Power on Canals, Rail-Ways, and Turnpike-Roads—Table of the Maximum Day's Work of a Horse on Canals, on Rail-ways, and on Turnpike-Roads—Tables of the Strength and Weight of Rails for Rail-ways—Table of the Weight and Bulk of Goods, Minerals, &c.

TABLE I.

Maximum Power of the Steam of a Cubic Foot of Water, in High Pressure Steam Engines.

Temperature of Steam.	Total force of Steam, in inches of Mercury.	Force of Steam, in lbs. per square inch, above the atmosphere.	Maximum Mechanical Power of the Steam of a Cubic foot of Water, in lbs. raised one foot high. When working at full pressure.	Acting expansively.	Proportion of the stroke to cut off the Steam to obtain the Maximum by expansion.	Pounds of Newcastle Coal to convert 1 cubic foot of Water into Steam.
	inches.	lbs.	lbs.	lbs.		lbs.
220°	35	2·5	negative.	negative.		8·5
234½	45	7·4	287,000			8·67
251	60	14·8	864,000	985,000	$\frac{3}{4}$	8·87
275	90	29·7	1,495,000	1,927,000	$\frac{7}{18}$	9·16
292·8	120	44·5	1,830,000	2,540,000	$\frac{1}{2}$	9·37
307·7	150	59·3	2,054,000	2,988,000	$\frac{9}{20}$	9·55
320·2	180	74·2	2,202,000	3,326,000	$\frac{5}{17}$	9·7
343·6	240	104	2,444,000	3,832,000	$\frac{3}{8}$	9·98

TABLE I.—The first table shows the whole power of the steam of a cubic foot of water, when generated at different temperatures, in pounds raised one foot high, acting in a high pressure engine. The 6th column shews what proportion of the stroke the piston should work at full pressure, to obtain the maximum power by working expansively. But to obtain the greatest useful effect, the full pressure will require to be continued longer; and to an extent which depends on the quantity of friction of the additional machinery necessary to produce the useful effect. An engine ought to be made so that the communication between the cylinder and boiler could be cut off at any part of the stroke, from the one given in the table to full pressure, at the pleasure of the attendant, or according to the stress on the engine; instead of the usual method of straightening the steam passage by that bungling contrivance which has been very properly termed a *throttle valve*. It ought to be clearly understood, that every thing which interrupts the passage of the steam to the cylinder wastes its power: theory had rendered us aware of this circumstance (see p. 83); but a valve of the kind we propose, has been used for some time, and we understand it to be the invention of Mr. Joshua Field. The force of the steam at different temperatures was taken from Mr. P. Taylor's table;* the power was calculated by the rules, p. 79; and the quantity of fuel by the rule, p. 78.

* Philos. Mag. vol. lx. p. 452.

TABLE II.

Maximum Power of the Steam of a Cubic Foot of Water, in a Condensing Steam Engine.

Temperature of Steam.	Total force of Steam, in inches of Mercury.	Force of Steam, in lbs. per square inch above the atmosphere.	Maximum Mechanical Power of the Steam of a cubic foot of Water, in lbs. raised one foot high. When working at full pressure.	Acting expansively.	Proportion of the stroke to cut off the Steam to obtain the Maximum expansively.	Pounds of Newcastle Coal to convert 1 cubic foot of Water into Steam.
	inches.	lbs.	lbs.	lbs.		lbs.
220°	35	2·5	2,134,000	3,350,000	$\frac{4}{11}$	8·5
234·5	45	7·4	2,230,000	3,636,000	$\frac{15}{44}$	8·67
251	60	14·8	2,366,000	3,961,000	$\frac{7}{33}$	8·87
275	90	29·7		4,379,000	$\frac{10}{34}$	9·16
292·8	120	44·5		4,590,000	$\frac{2}{7}$	9·37
307·7	150	59·3		4,819,000	$\frac{10}{36}$	9·55
320·2	180	74·2		4,932,000	$\frac{3}{11}$	9·7
343 6	240	104		5,162,000	$\frac{4}{15}$	9·98

TABLE II.—This table shews the same things for the condensing steam engine; and the same remarks respecting the manner and point where the steam should be cut off, apply to this engine: only it is necessary to add, that for a condensing engine to work with effect, either expansively or otherwise, the quantity of injection water should be proportioned to the quantity of steam to be condensed: most of the figures we have seen described, by the little instrument called the indicator, shew that when the engine is working at full pressure, either the injection or the air pump is deficient. If the regulation of the injection and stroke of the air pump were perfect, the lines indicating the rarefaction in the cylinder ought to coincide.

In either species of engine, if the steam be cut off at an earlier part of the stroke than that we have given, the piston will have to be dragged a part of the stroke by the fly wheel or its equivalent.

Table II. was calculated by the rules p. 91 and p. 78.

It is worthy of remark that our table gives $\frac{4}{13}$ of the stroke as the proper point to cut it off the steam when it is worked at 343 degrees, or 8 atmospheres; therefore, in a Woolf's engine for this temperature, the second cylinder should be about 4 times the capacity of the first; this we believe practice has informed them is the best proportion, and the proportions for other temperatures are found in like manner by the table.

TABLE III.

Quantity of Coals equivalent to the Horse Power of 33,000 *lbs. raised one foot per minute in High Pressure Steam Engines, when the greatest possible effect is obtained.*

Temperature of Steam.	Total force in inches of Mercury.	Force in lbs., per square inch above the atmosphere.	Quantity of Coal equivalent to a Horse Power.		Pounds raised one foot high equivalent to the immediate power of the Steam produced by 84lbs. of Coal.	
			When working at full pressure.	When acting expansively.	When working at full pressure.	When working expansively.
	inch.	lbs.	lbs.	lbs.	lbs.	lbs.
234·50	45	7·4	480		2,780,000	
251	60	14·8	163	143	8,200,000	9,300,000
275	90	29·7	98	77	13,700,000	17,700,000
292·8	120	44·5	82	59	16,600,000	22,700,000
307·7	150	59·3	74	51	18,000,000	26,200,000
320·2	180	74·2	70	48	19,200,000	28,700,000
343·6	240	104	65	41½	20,500,000	32,000,000

Table III.—This table is formed from Table I., in the same manner as is shewn in the examples, p. 80, for the pounds of coal equivalent to the day's work of a horse, of the steam engine or elementary horse power; and the pounds raised one foot high by a bushel of 84 lbs. of coal, is also found by proportion from the first table, and it is the whole power of the engine. To obtain the useful effect, the friction of the additional parts necessary to produce that effect, must be deducted.

TABLE IV.

Quantity of Coals equivalent to the Horse Power of 33,000lbs. raised one foot per minute in Condensing Steam Engines, when the greatest possible effect is obtained.

Temperature of Steam.	Total force in inches of Mercury.	Force in lbs., per square inch above the atmosphere.	Quantity of Coal equivalent to a Horse Power.		Pounds raised one foot high equivalent to the immediate power of the Steam produced by 84 lbs. of Coal.	
			When working at full pressure.	When working expansively.	When working at full pressure.	When working expansively.
	inches	lbs.	lbs.	lbs.	lbs.	lbs.
220°	35	2·5	63½	40½	21,000,000	33,100,000
234·5	45	7·4	62	38¼	21,400,000	35,200,000
251	60	14·8	60	35¾	22,400,000	37,500,000
275	90	29·7		33½		40,000,000
292·8	120	44·5		32½		41,000,000
307·7	150	59·3		32		42,400,000
320·2	180	74·2		31½		42,700,000
343·6	240	104		31		43,500,000

Table IV.—This table is formed from Table II., in the same manner as Table III. is formed from Table I.

Remarks on Tables III. and IV.—The columns shewing the pounds an engine ought to raise one foot high, by the heat of one bushel of coals, were

added, chiefly for the purpose of comparison with actual practice. Now, it is stated, that after the most impartial examination for several years in succession, it was found that Woolf's engine at Wheal Abraham Mine, raised 44 millions of pounds of water, one foot high, with a bushel of coals.* And, "the burning of one bushel of good Newcastle or Swansea coals, in Mr. Watt's reciprocating engines, working more or less expansively, was found, by the accounts kept at the Cornish mines, to raise from 24 to 32 millions of pounds of water one foot high; the greater or less effect depending upon the state of the engine, its size, and rate of working, and the quality of the coal." †

We shall further add the results of half a year's reports taken, without selection, from Messrs. Leans' Monthly Reports on the work performed by the steam engines in Cornwall, with each bushel of coals. The numbers shew the pounds of water raised one foot high with each bushel, from Jan. to June, 1818.‡

	January.	February.	March.	April.	May.	June.
	lbs. raised one foot.	lbs. raised one foot.	lbs. raised one foot.	lbs. raised one foot.	lbs. raised one foot.	lbs. raised one foot.
22 to 25 Common Engines average - - - -	22,188,000	22,424,000	21,898,000	22,982,000	23,608,000	23,836,000
Wheal Vor (Woolf's Engine) - - - - -	30,834,000	26,158,000	29,511,000	26,064,000	29,032,000	30,336,000
Wheal Abraham (ditto)	41,847,000	35,364,000	30,445,000	32,723,000	31,520,000	34,352,000
Ditto (ditto)	27,942,000	28,000,000	26,978,000	23,626,000	29,702,000	34,846,000
Wheal Unity (ditto)	31,900,000	32,306,000				
Dalcoath Engine - -	42,622,000	41,354,000	40,499,000	41,888,000	38,233,000	38,143,000
Wheal Abraham Engine	32,239,000	36,180,000	35,715,000	33 934,000	33,714,000	34,291,000
United Mines Engine -	36,396,000	31,830,000	31,427,000	33,564,000	33,967,000	30,105,000
Treskirby Engine - -	38,733,000	39,375,000	41,867,000	41,823,000	40,615,000	42,098,000
Wheal Chance Engine	28,496,000	32,319,000	33,594,000	33,932,000		35,797,000

* Millington's Natural and Experimental Philosophy, p. 346.

† Watt's Notes on Robison's Mech. Philosophy, vol. ii. p. 145.

‡ Philosophical Magazine, vol. li. and lii.

These numbers are less than the immediate power of the engines, by the friction and loss of effect in working the pumps; hence, in comparing them with our table, it will be evident that we have made our calculations from such data that they can be realised in practice. We know, from our own experience, that a cubic foot of water can be converted into steam equal in force to the atmosphere, with 7 lbs. of Newcastle coal; but we also know the attention necessary to produce that effect, and therefore have assumed that $8\frac{4}{10}$ lbs. will be required for that purpose. Our object is to shew what is attainable, and what ought to be attained in practice.

TABLE V.

A Table shewing the Effects of a Power of 100 *lbs. at different velocities, on Canals, Rail-Roads, and Turnpike-Roads.*

Velocity of Motion.		LOAD MOVED BY A FORCE OF TRACTION * OF 100 lb.					
		On a Canal.		On a Level Rail-way.		On a Level Turnpike-road.	
Miles per hour.	Feet per second.	Total mass moved. lbs.	Useful Effect. lbs.	Total mass moved. lbs.	Useful Effect. lbs.	Total mass moved. lbs.	Useful Effect. lbs.
$2\frac{1}{2}$	3·66	55,500	39,400	14,400	10,800	1,800	1,350
3	4·40	38,542	27,361	14,400	10,800	1,800	1,350
$3\frac{1}{2}$	5·13	28,316	20,100	14,400	10,800	1,800	1,350
4	5·86	21,680	15,390	14,400	10,800	1,800	1,350
5	7·33	13,875	9,850	14,400	10,800	1,800	1,350
6	8·80	9,635	6,840	14,400	10,800	1,800	1,350
7	10·26	7,080	5,026	14,400	10,800	1,800	1,350
8	11·73	5,420	3,848	14,400	10,800	1,800	1,350
9	13·20	4,282	3,040	14,400	10,800	1,800	1,350
10	14·66	3,468	2,462	14,400	10,800	1,800	1,350
13·5	19·9	1,900	1,350	14,400	10,800	1,800	1,350

* The force of traction on a canal varies as the square of the velocity; but the mechanical power necessary to move the boat, increases as the cube of the velocity. On a rail-road or turn-

TABLE V.—This table is to shew the work that may be performed by the same mechanical power, at different velocities, on canals, rail-roads, and turnpike-roads. Ascending and descending by locks on canals, may be considered equivalent to the ascent and descent of inclinations on rail-roads and turnpike-roads. The load carried, added to the weight of the vessel or carriage which contains it, forms the total mass moved; and the useful effect is the load. To find the effect on canals at different velocities, the effect of the given power at one velocity being known, it will be as $3^2 : 2{\cdot}5^2 :: 55{,}500 : 38{,}542$. The mass moved being very nearly inversely as the square of the velocity.

This table shews, that when the velocity is 5 miles per hour, it requires less power to obtain the same effect on a rail-way than on a canal; and we have added the lower range of figures to shew the velocity at which the effect on a canal is only equal to that on a turnpike-road. By comparing the power and tonnage of steam vessels, it will be found that the rate of decrease of power by increase of velocity, is not very distant from the truth; but we know that in a narrow canal the resistance increases in a more rapid ratio than as the square of the velocity: only, we have not time to spare to follow up the inquiry at this moment. Other tables of a similar kind have been published, and we find our column exhibiting the useful effect on canals nearly agrees with that of Mr. M., the ingenious author of a series of essays

pike, the force of traction is constant; but the mechanical power necessary to move the carriage, increases as its velocity. See Tables V. and VI. and p. 146.

on the subject, which first appeared in the Scotsman; but we differ respecting rail-ways, his being more in favour of rail-roads. From Mr. Sylvester's table this differs very considerably: he has underrated the effect on canals as much as he has overrated the effect on rail-ways and common roads. See Report on Rail-Roads, Liverpool, 1825.

TABLE VI.

A Table shewing the Maximum Quantity of Labour a Horse of avervge strength is capable of performing, at different velocities, on Canals, Rail-Ways, and Turnpike-Roads.

Velocity in Miles per hour.	Duration of the Day's Work at the preceding velocity.	Force of Traction in lbs.	Useful Effect of one Horse working one day, in tons drawn one mile.		
			On a Canal.	On a level Rail-way.	On a good level Turnpike-road.
miles.	hours.	lbs.	tons.	tons.	tons.
$2\frac{1}{2}$	$11\frac{1}{2}$	$83\frac{1}{3}$	520	115	14
3	8	$83\frac{1}{3}$	243	92	12
$3\frac{1}{2}$	$5\frac{9}{10}$	$83\frac{1}{3}$	153	82	10
4	$4\frac{1}{2}$	$83\frac{1}{3}$	102	72	9
5	$2\frac{9}{10}$	$83\frac{1}{3}$	52	57	7·2
6	2	$83\frac{1}{3}$	30	48	6·0
7	$1\frac{1}{2}$	$83\frac{1}{3}$	19	41	5·1
8	$1\frac{1}{8}$	$83\frac{1}{3}$	12·8	36	4·5
9	$\frac{9}{10}$	$83\frac{1}{3}$	9·0	32	4·0
10	$\frac{3}{4}$	$83\frac{1}{3}$	6·6	28·8	3·6

TABLE VI.—In re-examining the table in p. 72, it was obvious that there is a maximum depending upon the duration of the day's work, and on which is founded this table; and the investigation of the maximum is given in the next page. Where horse power is employed for the higher velocities, the animals

ought to be allowed to acquire the speed as gradually as possible at the first starting. This simple expedient will save the proprietors of the horses much more than they are aware of; and it deserves their attention to consider the best mode of feeding and training horses for performing the work with the least injury to their animal powers.

To compare our table with practice at the higher velocities, it will be necessary to have the total mass moved, which is one-third more than the useful effect in the table. Now, the actual rate at which some of the quick coaches travel, is 10 miles an hour; the stages average about 9 miles; and a coach with its load of luggage and passengers amounts to about 3 tons; therefore, the average day's work of 4 coach horses is 27 tons drawn one mile, or $6\frac{3}{4}$ tons drawn one mile by one horse. The table gives 3·6 tons, added $\frac{1}{3}$ of $3{\cdot}6 = 4{\cdot}8$ tons drawn one mile for the extreme quantity of labour for a horse at that speed, upon a good level road; from which should be deducted the loss of effect in ascending hills, heavy roads, &c. which will make the actual labour performed by a coach-horse average about double the maximum given by the table. The consequences are well known.

According to Mr. Bevan's observations, the horses on the Grand Junction Canal draw 617 tons one mile, at the velocity of 2.45 miles per hour. See p. 151.

We have shewn (in p. 68) that the immediate power of a horse is $250\, v \left(1 - \frac{v}{V}\right)$, and, when the

weight of the vessel or carriage is to the weight of the load, as n: 1, we have $\frac{250\,v\left(1-\frac{v}{\mathrm{V}}\right)}{1+n}$ = the effective power; and d being the hours the horse works in one day, the day's work will be $\frac{250\,d\,v\left(1-\frac{v}{\mathrm{V}}\right)}{1+n}$ in lbs. raised 1 mile, and $250\left(1-\frac{v}{\mathrm{V}}\right)$ = the force of traction in lbs. But if the force were immediately applied, the value of V would be $\frac{14{\cdot}7}{\sqrt{d}}$; and to find the value when the waggons alone are moved, we have $1 : \frac{1}{\sqrt{1+n}} :: \frac{14{\cdot}7}{\sqrt{d}} : \frac{14{\cdot}7}{\sqrt{d\,(1+n)}} = \mathrm{V}$; whence the day's work is $\frac{250\,d\,v}{1+n}\left(1-\frac{v\sqrt{d\,(1+n)}}{14{\cdot}7}\right)$; which is a maximum when $\frac{96}{v^2\,(1+n)} = d$. Consequently, when the velocity is given, we have $\frac{96}{v^2\,(1+n)}$ = the duration of the day's work in hours; and $\frac{8000}{v(1+n)^2}$ = the effective day's work; and $250\left(1-\frac{9{\cdot}8}{14{\cdot}7}\right) = 83\frac{1}{3}$ lbs. But we may assume n to be always so near $\frac{1}{3}$, as not to affect the result; and then, $\frac{72}{v^2} = d$, and $\frac{4500}{v}$ = the day's work in lbs., or very nearly $\frac{2}{v}$ tons raised one mile. This being combined with the numbers of the preceding table, gives the effect of a horse on canals, rail-roads, and turnpike-roads.

TABLE VII.

A Table of the Dimensions and Weight of Cast Iron Rails for Edge Rail-Roads. See p. 126, Chap. VII.

Distance between the supports in feet.	Depth of Rail in inches.	Total Load on each Wheel of the Carriage in Tons.								
		½ ton.	¾ ton.	1 ton.	1⅛ tons.	1¼ tons.	1⅜ tons.	1½ tons.	2 tons.	2½ tons.
		Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.	Weight of Rail. lbs.
2	3¾	10½	15¾	21	23¾	26¼	29	31½	42	52½
3	4	19¼	29	38½	43½	48	53	57¾	77	96¼
3½	4⅜	24½	36¾	49	55	61½	67½	73½	98	122½
4	4⅝	29½	43¾	59	66½	74	81½	88½	118	147½
4½	4⅞	35	52½	70	79	88	96½	105	140	175
5	5⅛			82	92¼	103	113	123	164	205
5½	5⅜			94¾	107	119	131	142¼	189½	237
6	5⅝			108	122	135	148	162	216	270
7	6			134½	152	169	186	201¾	269	336¼
8	6½			166½	187	210	230	249¾	333	415¼
9	6⅞			198	223	250	275	297	396	495
10	7¼			232	261	290	320	348	464	580
		1 in.	1½ in.	2 in.	2¼ in	2½ in.	2¾ in.	3 in.	4 in.	5 in.
		Breadth of upper Surface of the Rail in inches.								

These dimensions and weights are given for ordinary purposes; but for important works the strength ought to be increased, so as to lessen the risk of failure from percussion (see p. 127). Where the increase is proposed to be about one-third, and the addition is proposed to be made to the breadth, to give more lateral strength to the rail, the table will still serve the purpose of finding the weight and

depth for the rails, because it is only to consider the load on a wheel to be increased to one-third more, and take the corresponding strength for the rails. For carriages on springs and steam carriages, consider the stress on each wheel only two-thirds of the actual load upon it, which will be about an equivalent excess of strength for this case.

TABLE VIII.

A Table of the Dimensions and Weight of Malleable Iron Rails for Edge Rail-Roads. See p. 130, *Chap. VII.*

Distynce between the supports in feet.	Depth of Rail in inches.	Total Load on each Wheel of the Carriages in Tons.								
		½ ton.	¾ ton.	1 ton.	1⅛ tons.	1¼ tons.	1⅜ tons.	1½ tons.	2 tons.	2½ tons.
		Weight of Rail.	Weight of Rail.	Weight of Rail.	Weight of Rail.	Weight of Rail.	Weight of Rail.	Weight of Rail.	Weight of Rail.	Weight of Rail.
feet.	inch.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
2	2½	6½	9¾	12¾	14½	16	17	19¼	25½	32
3	3	12	18	24	27	30	33	36	48	60
3½	3⅛	13½	20¼	26¾	30¼	33½	37	40¼	53½	67
4	3⅝	18½	37¾	37	42	46½	51	55½	74	92½
4½	3⅞	22¼	33½	44½	50	56	61½	66¾	89	111¼
5	4			51	57½	64	70	76½	102	127½
5½	4¼			59¾	68	75	82½	89¾	119½	149½
6	4⅜			67	75½	84	92	100½	134	167½
7	4¾			85	96	107	117	127½	170	212½
8	5			102	115	128	140	153	204	255
9	5⅜			123½	140	154	169	186¼	247	309¾
10	5⅝			143½	162	180	196	216¼	287	359¾
		1 in.	1½ in.	2 in.	2¼ in.	2½ in.	2¾ in.	3 in.	4 in.	5 in.
		Breadth of upper Surface of the Rail in Inches.								

In a rail-way for ordinary purposes the weight and size may be taken from the table; but for public

rail-ways the total load on each wheel should be increased one-third, and then the corresponding size and weight taken from the table. Where the heaviest carriages are on springs, or floating pistons, two-thirds of the actual load on each wheel may be considered the stress on the rail for ordinary purposes, and the actual load should be considered the stress for public roads.

TABLE IX.

A Table of the Weight which occupies a Cubic Foot, and the Space occupied by a Ton of different Substances.

Description of Substance.	Weight in a cubic foot of Space.	Space occupied by one tun.
	lbs.	cubic feet.
Lead (cast in pigs)............	567	4
Iron (cast in pigs)............	360	6¼
Limestone or Marble (in blocks)..	172	13
Granite (Aberdeen, in blocks)..	166	13½
Granite (Cornish, in blocks)....	164	14
Sandstone (in blocks)..........	141	16
Portland Stone (in blocks)......	132	17
Potter's Clay	130	17
Loam or strong soil	126	18
Bath Stone (in blocks)	123½	18
Gravel......................	109	21
Sand	95	23½
Bricks (common stocks dry)....	93	24
Culm	63	36
Water (river)................	62½	36
Splint Coal	57	39½
Oak (seasoned)	52	43
Coal (Newcastle Caking)	50	45
Wheat......................	48	47
Barley......................	38	59
Red Fir	38	59
Hay (compact, old)	8	280

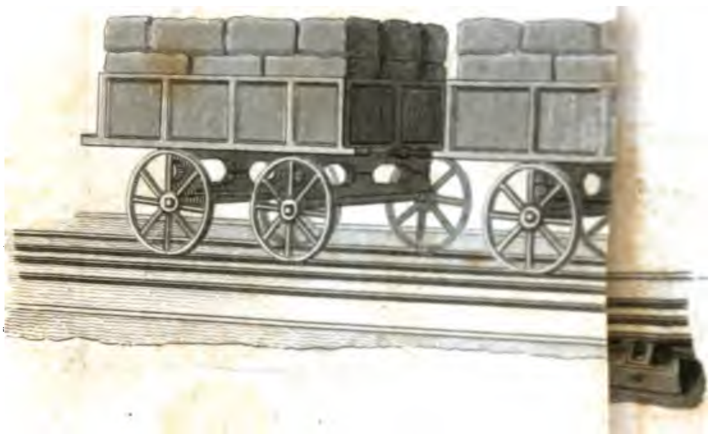
DESCRIPTION OF THE PLATES.

PLATE 1.

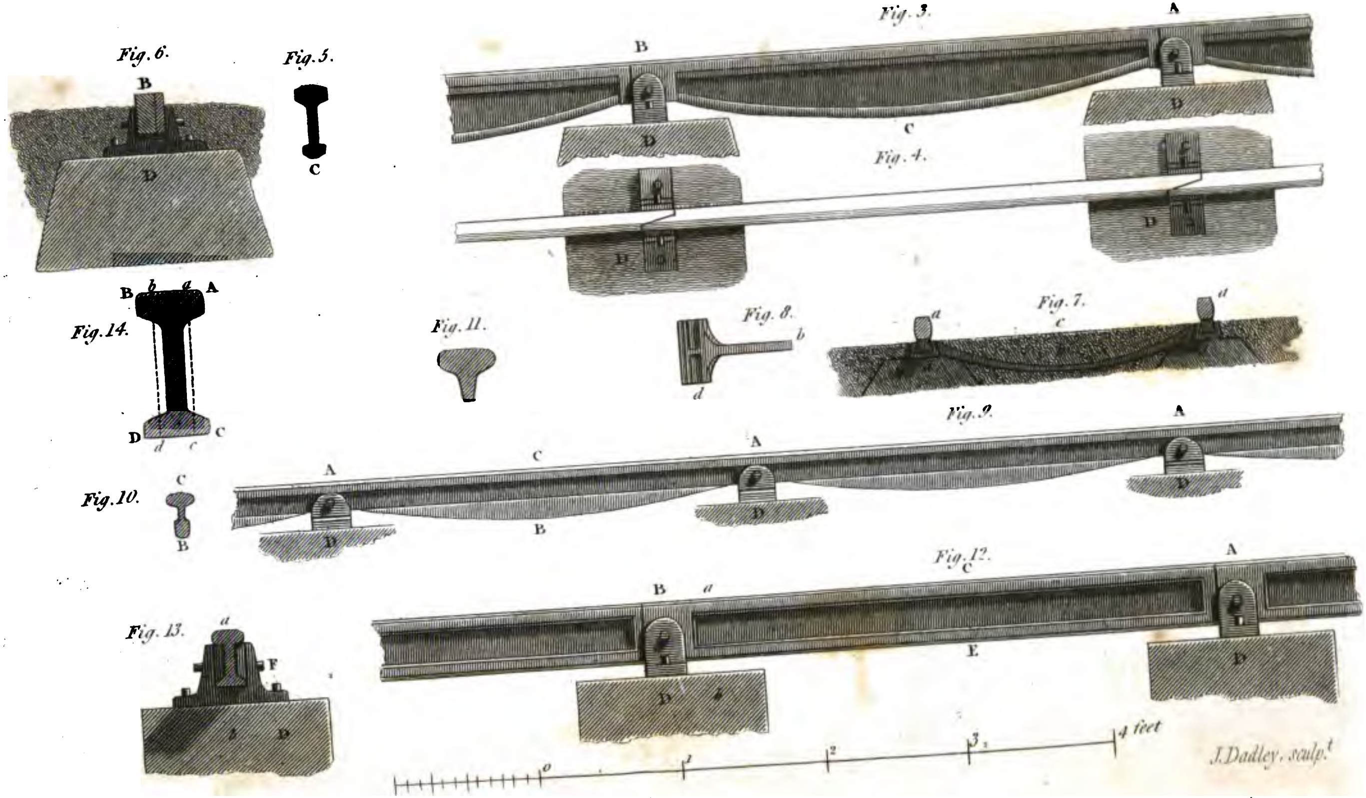
Fig. 1. This figure is to explain the nature of a rail-road. The road has a double set of rails or tracks, and is of the edge-rail kind; part of one of the tracks is supposed to be taken up to shew the internal arrangement, The iron rails for the wheels of the carriages to run upon are supported by blocks of stone marked *a a*. The horse path is formed with gravel or broken stone. See p. 1.

Fig. 2. This is a sketch of the steam carriage employed on the Hetton railway. A is the boiler, and B B the steam cylinders; the fire-place is within the boiler, and F is the entrance to it; C is the chimney; D D the floating pistons which support the carriage on the axles, and answer as springs in making it press equally on the rails. As the moving force is not equal at the same time on the wheels of both axles, it is necessary to connect the axles by a pitch chain G, working into toothed wheels on the axles. The water for supplying the boiler, and the coals at *b* for the fire, are carried by a small carriage, called the *tender;* I is the water barrel, and *a* is a hose pipe which conveys the water to the force pump H, which is worked by the engine; W W are coal waggons, each of which carries 53 cwt. of coals. From 13 to 17 of these waggons are drawn in a train by one steam carriage; they are connected by the short chains *c c*. The connecting rods which communicate the power from the pistons to the wheels of the steam carriage are attached to the wheels, so that one piston is at half the length of its stroke, when the other is at the commencement of its stroke. See pp. 13 and 74.

PLATE I.



T. Tredgold. del.



J. Dudley, sculp.t

T. Tredgold, del.t

Published by J. Taylor, at the Architectural Library, 59 High Holborn, 1825.

PLATE II.

Fig. 3. Is a side view of a cast iron edge-rail, supported by blocks of stone D D; and fig. 4 is a plan of the rail shewing the scarf joints where the ends of the rails meet in the iron chair which supports them; fig. 5 is a cross section of the rail at C, the middle of its length; fig. 6 is a cross section at B, through the joint, chair, and supporting block. See pp. 12 and 29.

Fig. 7. Is a cross section of the rails and road of the Penrhyn slate quarries; the rails *a a* have a dove-tailed piece cast upon them, which fits a corresponding groove in the cross sill *b*, which is of cast iron, and passes under the horse path *c*; fig. 8 is a plan of one end of the cross sill, shewing the grooves. See pp. 25 and 29.

Fig. 9. Is a side view of part of a malleable iron edge-rail, supported by cast iron chairs at A A A, on blocks of stone D D D, 3 feet apart; fig 10 is a cross section at C B, the middle between the blocks; fig. 11 is a cross section of another form proposed for malleable iron rails. See pp. 13, 31, and 128.

Fig. 12. Is a side view of an edge rail of uniform depth, so as to unite the properties of stiffness and strength; fig. 13 is a section at *a b*, shewing the form of the section of the rail, and the chair which supports it at the joint. See pp. 125 and 172.

Fig. 14. This is an enlarged section of an edge-rail, to shew the disposition of the parts which gives the greatest degree of strength. If the rectangle *a b d c* contain the same quantity of matter, the strength of the rail of the form of the section A B D C is to the strength in the form of the rectangle as $1\frac{3}{4}$ is to one. The ordinary mode of collecting the bulk of matter in the part which is exposed to tension, has never been adopted in designing rails; indeed, the opposite error has been chiefly followed. See pp. 126, 130, and 172.

PLATE III.

Fig. 15, 16 and 17. These figures are to illustrate the advantage of long rails. The portion of rail C D, fig. 16, is nearly twice as strong as a short rail A B, fig. 15; and fig 17. is to shew how the supports of a long rail should be disposed to render its parts nearly of an equal strength. See p. 124.

Fig. 18. This is a cross section of a tram-road, shewing the form of the rails at B B, and the mode of securing them to the blocks by nails driven into wooden plugs inserted in the stone blocks C C; A is the horse path, (see pp. 15, 32, and 43.) The internal angle, formed by the guide and the bed of the rail, should be curved, to give the wheels a tendency to keep clear of the guides.

Fig. 19. Shews half a tram-rail having a rib C on the under side to strengthen it; A is the guide, and B the bed of the rail on which the wheels run. See pp. 15, 33, and 136.

Fig. 20, 21, and 22. Shew Le Caan's mode of fixing tram-plates. See p. 33.

Fig. 23, Represents a wheel for an edge rail-road, to illustrate the mode of calculating its strength. See p. 96.

Fig. 24. This figure is to shew the form of the rim for the wheels for an edge rail-road, so that there may be a tendency to run clear of the guiding flaunches of the wheel. See p. 43.

Fig. 25. Shews the mode of disposing the matter of the spokes, to render them as strong as possible, without rendering them difficult to cast. See p. 96.

Fig. 15.

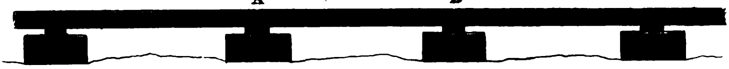
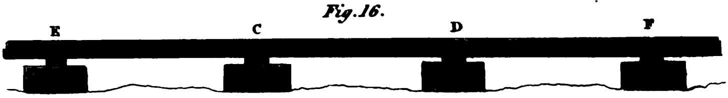


Fig. 16.



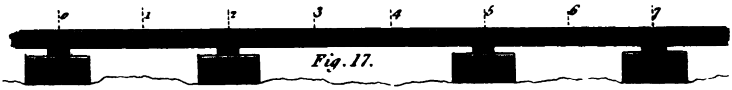


Fig. 17.

Fig. 19.

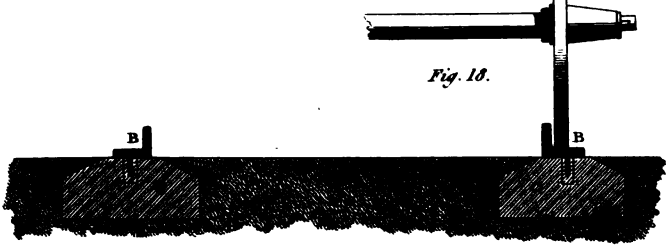


Fig. 18.

Fig. 20.

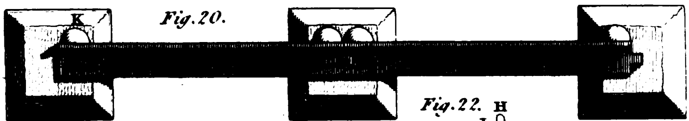


Fig. 22.

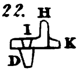


Fig. 21.

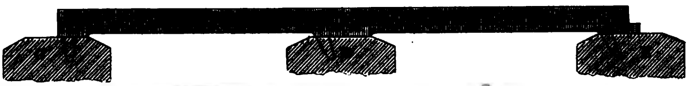


Fig. 23.

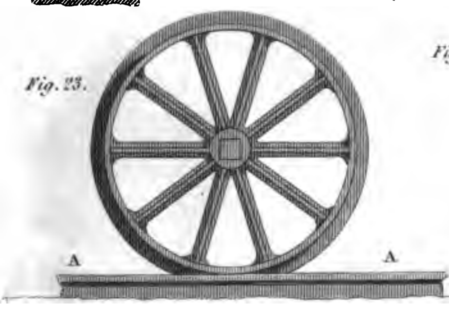


Fig. 24.

Fig. 25.

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Fig. 26.

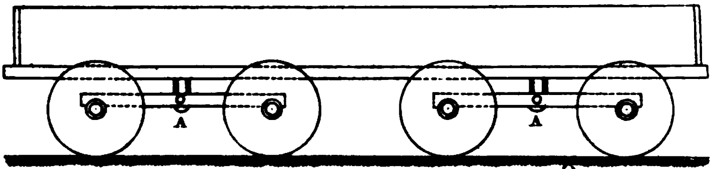

Fig. 28.

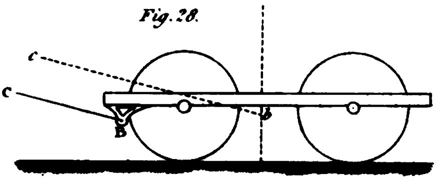

Fig. 27.

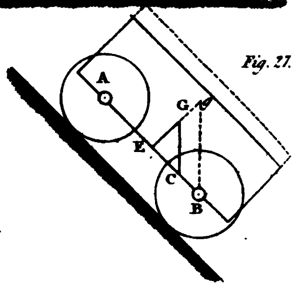

Fig. 30.

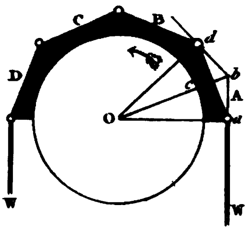

Fig. 29.

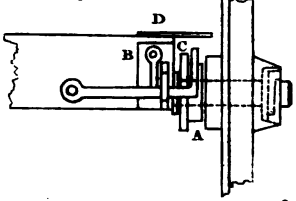

Fig. 31.

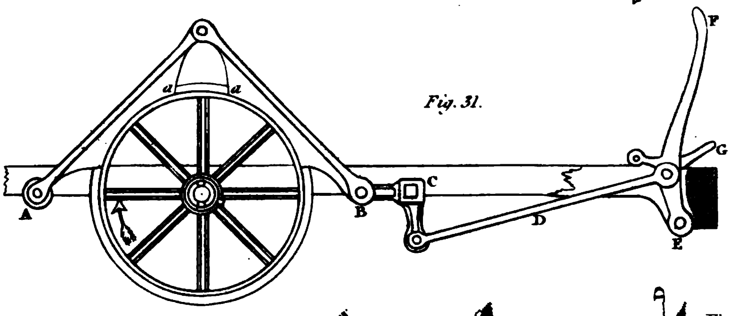

Fig. 32

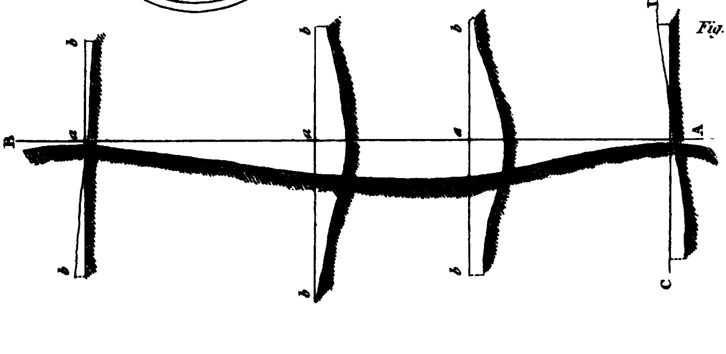

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PLATE IV.

Fig. 26. A diagram to shew how a waggon may be made with 8 wheels, so that the stress of each wheel on the rails of a rail-road may be equal. The body of the waggon rests on the wheel frames at A A, and is connected to them by an axis on which the frames turn when, from any inequality, the axes of the wheels are not in the same plane. See p. 94.

Fig. 27. A diagram to shew the stress upon the lower axle of a waggon on an inclined plane; G is the centre of gravity of the load, and the vertical G C the direction of the stress. If the centre of gravity raised to *g*, the whole stress is on the lower axle. See p. 101.

Fig. 28. When a waggon is drawn by a horse, the horse acts with most advantage when the line of traction B C is nearly perpendicular to his shoulder; and this may be effected by attaching the traces to some point B below the level of the axis, if the wheels be too high to gain the direction without this expedient. The best direction, as regards the friction of the waggon, is, when the line is above the level of the axis, as *b c*. See p. 103.

Fig. 29. A guard to keep the wheel in its place if the linch-pin should be broken or lost; A is the groove in the nave, into which the guard C is held by the swivel B; the collar C of the guard should not touch the sides or bottom of the groove when the wheel is retained in its proper place by the linch pin; D is a plate to keep out dust. See p. 105.

Fig. 30. A diagram to illustrate the theory of brake-wheels. See p. 107.

Fig. 31. A brake or convoy for stopping or retarding the descent of carriages on rail-roads. By means of the lever F, which turns on the centre E, the blocks of wood *a a* are pressed on the wheel or relieved from it. A ratchet G is intended to hold the lever at any desirable degree of pressure. The lever and connecting rod is supposed to be in the middle of the breadth of the carriage, and to act by means of the axis C on a brake on each side of the carriage. The motion of the wheel should be from A to B, as shewn by the arrow. See p. 102.

Fig. 32. A diagram to shew the best mode of levelling and drawing the results on a plan for determining the exact line best adapted for a rail-road. See p. 114.

INDEX.

THE END.

J. B. Nichols, and Son, 25, Parliament Street.